Consultation on the Consequences of Offshore Oil Production on Offshore Fish Stocks and Fishing Operations

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Canadian Technical Report of

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(Organized by Marine Environment and Ecosystems Subcommittee of Canadian Atlantic Fisheries Scientific Advisory Committee, at the Bedford Institute of Oceanography, 27-28 October, 1980)

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CONTENTS

	Page
Abstract/Résumé	4
Chairman's Introduction	5
Executive Summary	7
"Probable statistics of accidental release of hydrocarbons" by Tom Dexter (EMR/RMB at BIO)	12
"Oil behaviour offshore and concentrations of biota" by John Vandermeulen (DFO/OSS/MEL at BIO)	22
"From probabilities concerning the accidental release of oil and its physiological consequences, what kind of observational programs would be required to detect the biotic effects?" by Mike Sinclair (DFO/FM/MFD at BIO)	54
"Recruitment variability - can we detect the effect of oil pollution?" by Dan Ware (DFO/OSS/MEL at BIO)	64
"Effect of offshore oil on fishing activities" by D.J. Scarratt (DFO/FM at St. Andrews)	74
"Offshore oil developments: countermeasures for oil spills" by R.H. Cook (DFO/FM at St. Andrews)	78
Rapporteurs Report	85

ABSTRACT

Longhurst, A.R. (Ed.) Consultation on the Consequences of Offshore Oil Production on Offshore Fish Stocks and Fishing Operations. Canadian Technical Report of Fisheries and Aquatic Sciences. Tech. Report No.

This document records the proceedings of an internal DFO Consultation on the probable effects of offshore oil operations on offshore fish stocks and fishing operations. Topics covered included: probable statistics of accidental release of hydrocarbons; the levels of contamination to be expected in water and biota; the observational programs needed to detect the biotic effects; the probability of an effect on fish recruitment; the consequences for offshore fishing; and the effectiveness of various countermeasures.

The views expressed are the personal opinions and interpretations of the individuals concerned.

RÉSUMÉ

Longhurst, A.R. (Ed.) Consultation on the Consequences of Offshore Oil Production on Offshore Fish Stocks and Fishing Operations. Canadian Technical Report of Fisheries and Aquatic Sciences. Tech. Report No.

Ce qui suit est le compte rendu d'une consultation qui eut lieu au sein du MPO sur les effets probables d'une exploitation pétrolière sur les stocks de poissons et la pêche en haute mer. Parmi les sujets traités, on note: les probabilités statistiques d'échappements accidentels d'hydrocarbures; les niveaux de contamination anticipés de l'eau et des biocénoses; les observations nécessaires à la détection des effets biotiques; la probabilité d'un effet sur le recrutement des poissons; les conséquences sur la pêche hauturière; et l'efficacité de diverses contre-mesures.

Les opinions et interprétations avancées représentent le point de vue personnel des individus en cause.

INTRODUCTION

Responding to requests from several people both within DFO and in other Departments, MEES undertook a Consultation on the probable consequences for the offshore fishery of offshore hydrocarbon development at the Bedford Institute of Oceanography on 27-28 October 1980.

The objective of this Consultation was to draft a scientific opinion as to the probable consequences of the additional oil contamination to be anticipated as a result of offshore hydrocarbon production at Sable Island and on the Grand Banks.

Recognizing that this is a highly complex problem, leaving much more scope for speculation than certainty, it was decided to focus attention upon a very limited set of questions, which individual experts were invited to answer prior to an in-depth discussion. For this to be done, each speaker had to be asked to voice an opinion on a subject area wider than his own personal responsibility or research, and to extrapolate extensively from the literature.

It was decided not to discuss the distant-field effects of oil contamination at the coastline, and so discussion did not cover coastal fisheries, recreational beaches, ports and harbours, or wildlife. It was felt that these subjects had been much more comprehensively discussed in the past than the offshore consequences and were much better understood. This was not meant to imply that the inshore problems were less important than those offshore; in fact, during the discussions it became apparent that the general opinion was to the contrary.

Three points must be made about the Consultation to avoid subsequent misunderstanding:

1. The views expressed were the personal opinions and interpretations of the individuals concerned, and not the considered position of any organization or department.

2. The output from the Consultation does not represent, and cannot substitute for, a detailed study of the same set of problems done more formally and taking more time than two days to execute. However, it must be said that the general conclusions of such a study are unlikely to be very different from those expressed in this report.

3. No consideration was given during the Consultation to program requirements for the future to solve any of the uncertainties exposed, nor to recommendations for countermeasures in any of the scenarios likely to be encountered.

The Consultation took the following form: each contributing scientist was given a question in advance and was asked to address it during his presentation at the meeting. These presentations form the bulk of this report. Subsequent discussion was summarized by three Rapporteurs, and their comments are given in the last section.

The meeting was intended to be, as its title indicates, a scientific consultation on a subject about which much misinformation appeared to be current, so that a consensus might be expressed by at least one segment of the scientific community concerning the most probable consequences for the offshore fishery of developing Hibernia and Sable Island: therefore, no formal recommendations were made, nor would they have been appropriate. Nevertheless, if the persons involved represented the best available expertise for consultation then the conclusions to be drawn from their statements are self-evident. An Executive Summary is provided which, it is hoped, will make the outlines of the conclusions reached during the Consultation easy to acquire.

Alan Longhurst
Chairman

EXECUTIVE SUMMARY

1. What are the likely scales and frequency of accidental release of hydrocarbons from foreseeable developments off the east coast?

Developments in the Sable Island area are likely to be for gas, with minor amounts of light condensate. Gas will be piped ashore, and condensate will be accumulated and shipped by tanker. Oil spill size is therefore not likely to exceed 10,000 tonnes of light condensate.

On the Grand Banks, crude oil is light and sweet (low sulfur content) with a high proportion of volatiles. Production is likely to be by caisson-protected seabed well heads feeding a single riser to a floating storage vessel. Maximum likely blowout is 20,000 bbl/day, but it is anticipated wells would bridge in 5-20 days. Maximum probable spill would be the total loss of contents (M bbl) of storage vessel, or shuttle tanker loss. Offshore Labrador reserves are likely to be exclusively gas, but developments will probably be deferred 10-15 years due to environmental and technical limitations.

World-wide statistics suggest a frequency of blowouts exceeding 100 bbl to be about 1 per 250 wells. To date 172 wells have been drilled in east coast waters without mishap. Production wells have slightly higher spill rate and frequency than exploratory wells. An oil field the size of Hibernia might be expected to have a .25 probability of a blowout during the life of the field. Chronic oil spillage seems more likely to occur as a result of transhipment operations but no statistics were available. Shuttle tanker ballast water might be a source of chronic pollution.

2. What levels of oil contamination may be expected in water, sediments and what would be the physiological consequences for biota?

Concentrations of oil in water near or below a slick may be expected to be in the order of 10-200 ppb. Depending on mixing characteristics, these concentrations may exist throughout the water column (down to 100 m) and persist a few days or weeks. Hibernia oil, being light, will volatise readily and up to 40% will be lost to the atmosphere within 24 hours of release; however, the proportion of oil dissolved or dispersed in the water will increase in rougher seas.

Fish egg and larval mortality and abnormal larval development of vertebrates and invertebrates would be observed at these oil concentrations. Based on experiences with AMOCO CADIZ, benthic species might suffer mortality or physiological disruption in coastal areas. Routes by which bottom sediments might become contaminated are not clearly defined, but in shallow areas, oil concentrations in sediments might reach 10-100 ppm, and this would have physiological implications

for the benthos; however, water column stratification is strong on the Grand Banks and this might inhibit sediment contamination.

Phytoplankton production might be enhanced at low concentrations of oil in water, and inhibited when oil concentrations are high. Zooplankton growth might be depressed but existing data are equivocal. Teleost eggs and larvae are expected to be affected physiologically but current ignorance of the distribution in space and time makes prediction, and subsequent measurement of impact, difficult. It was suggested that effects might be more readily measurable using physiological, or clinical criteria, rather than gross assessments of deformities, or population reductions.

3. What kind of observational programs would be required to detect the effects on biota?

Effects fall into two categories: lethal and sublethal, each requiring different sampling and analytical techniques, but both would require baseline data.

Assessment of mortality requires estimates of population abundance and distribution before the event; however existing ichthyoplankton survey programs on the Scotian Shelf do not generate information of sufficient precision to allow assessment of mortality due to an oil spill. Analysis of Bay of Fundy sampling programs suggests a station density of the order of 1 per 100 sq nm would be required for each of 3 or 4 surveys for each stock of interest. Covering all breeding stocks on the Scotian Shelf and Grand Banks would require a major escalation of existing effort. Diversion of standard surveys in the event of an emergency would simply reduce the value of those programs without contributing meaningful data on the effect of the spill on the populations at risk.

Due to wide annual variability in populations, existing juvenile and pre-recruit surveys have very large confidence limits and it is unlikely that mortalities less than an order of magnitude more than normal would be detectable. Although precision of adult stock estimates is much better, it would still only be possible to detect mortality when it reached 25% in the 'best case' stock, and in most cases mortalities higher than 25% may well go undetected.

Monitoring for sublethal effects appears to have greater probability for success and likelihood of cost-effectiveness. Specific pre-event monitoring of representative samples of the population for selected indices of physiological well-being would be required. These could include physical parameters such as deformations and fish larval tail flexures as well as pathological or clinical measurements such as identification of histological changes, or enzyme activity. These should be additional to simple measurements of hydrocarbon body burdens.

Nevertheless, even with a good monitoring program in place, the impact of episodic major contamination may be difficult to distinguish from the cumulative effects of chronic discharges. None of the methodologies currently available seem likely to give estimates of loss which could be used for purposes of compensation to fishermen.

4. What is the likelihood that such effects would impair recruitment, and that such impaired recruitment would be separable from natural variation?

Hydrocarbons appear to be most toxic to early life-history stages of commercial species, and probably of all organisms.

Each fish stock has a more or less discrete spawning time and area mostly during spring and summer, though in all months some species may be expected to be spawning. The timing and location of spawning and subsequent distribution of larvae is imperfectly known for most stocks, but the area impacted by a spill is likely to be only a small fraction of the total area occupied by larvae. Natural annual variation on spawning success is such that even a 50-100% loss of a weak year-class will not have a detectable effect on recruitment to the commercial stock. A similar loss of an excellent year-class might affect recruitment but still not be measurable; except for stocks spawning in discrete, shallow areas, such a loss seems unlikely to occur.

A distinction must be made between 'no detectable effect' and 'no material effect' on the population. It is quite possible that a post-spill survey would yield numbers of dead, moribund or deformed larvae, but it is quite unlikely that this population loss could be measured in a statistically convincing manner and be shown to have a subsequent effect upon recruitment a number of years later, or upon the fishery over the normal lifetime of that year-class.

The one area of concern not resolved was that the concentration of hydrocarbon developments close to the edge of the continental shelf might result in concentration of spilled oil in biologically dynamic areas, and thus impact 'core' areas of larval distribution. It is not known whether larvae from all parts of their total area of distribution have equal chances of recruitment.

The effects of suppressed primary production, possibly caused by an oil spill, upon subsequent fish stock biomass will be undetectably small, or negligible.

5. What consequences for offshore fishing operations may be expected?

It seems unlikely that adult or commercial sized fish will be killed by oil development activities.

Because of lack of information it is difficult to predict exactly what might happen when a year-class of larvae is impacted by a spill: the most that could be expected is that it might be similar to that of a weak year-class entering a multi year-class fishery; thus, except in inshore waters or restricted stocks spawning in shallow water, it is unlikely that offshore oil discharges will have measurable impact on fish stocks or year-class success since such an effect could not presently be separated from natural variability.

Except in restricted or shallow waters, it seems unlikely that fish will be tainted by oil. It is possible that catches may be contaminated and possibly tainted if caught in oiled nets. Apart from the visible presence of oil, there are no established standards for rejecting contaminated catches.

There is high probability that spills on the Grand Banks may cause fouling of fishing gear which may in turn cause catch contamination. High volatility of oil may be offset by the high paraffin content which might cause the oil to become waxy at low temperatures.

The degree of interference to fishing operations by preemption of space cannot be predicted. Careful engineering should minimize or eliminate damage to, and loss of, fishing gear caused by under-water obstructions.

It is unlikely there will be any need to modify Canadian or foreign harvesting strategies except in the event of major spills causing extensive slicks which might require exclusion measures for a few days or weeks in order to protect gear from oiling.

Except for costs incurred by oiling of gear or probable damage, determining costs to the fishery of an oil spill will prove extremely difficult. Given that recruitment may be as much as 8-10 year post spill, and density-dependent factors may play a significant role a statute of limitations may prove troublesome. Two stock are considered to be particularly vulnerable: Georges Bank herring, because of small stock size and shallow restricted spawning areas; Grand Banks capelin, because they spawn in a single location and only 1 or 2 year-classes contribute to the fishery.

6. What will be the effects if any, of countermeasures?

The most effective countermeasures against episodic and chronic pollution are prevention and organization. Notwithstanding recent developments, booms seem likely to have only minimal effectiveness in containing oil offshore prior to recovery. Burning likewise may be of minimal practicability. Aerial application of dispersants might have some usefulness in dispersing slicks which would otherwise hazard fishing gear, but no clear opinion exists as to the subsequent biological impact. Dispersant spraying might minimize physical impact on the shorelines. Decision to use dispersants should be made on case-by-case basis.

Slick modelling and prediction should enable forecasting of likely trajectories and identification of threatened fishing areas.

Research and development should continue into countermeasures technology.

REPORT OF MEETING

1. WHAT ARE THE LIKELY SCALES AND FREQUENCY OF ACCIDENTAL RELEASE OF HYDROCARBONS FROM FORESEEABLE DEVELOPMENTS OFF THE EAST COAST?

Tom Dexter (EMR/RMB at BIO)

Anticipated Precautions

Before any of the more visible precautions and remedial measures taken to ensure that a "blowout" shall not occur are taken, the main prophylactic safeguards have already been observed. These are the stipulations laid down in the Canada Oil and Gas Drilling Regulations which prescribe standards of material and quantities to be used, training of crews and methods by which drilling of the well shall be conducted. They are comprehensive and stringent.

Regulations governing production, diving, installations and geophysical prospecting are in the mill and will be enacted in due course.

The control of underground pressures is the most important factor in the planning and conduct of oil and gas operations. Improper well control procedures can result in the sudden, uncontrolled escape of hydrocarbons commonly referred to as a blowout. Blowouts are the most spectacular, expensive and feared operational hazard. At best they result in costly delays in drilling or production programs and may lead to fires, explosions, casualties, serious property damage and pollution.

They can occur for a number of reasons, both during drilling operations and during workovers on producing wells (i.e where a well is opened up for remedial work etc.). Their occurrence is primarily due to failure to use, or failure of, final safety equipment following inability of the drilling mud column to counteract the natural pressure of the hydrocarbon reservoir and after operational preventive measures have been taken. Such measures are triggered by unexpectedly high formation pressure passing a slug of gas into the well bore thereby lowering the effective weight of the mud, or perhaps through lost circulation where some of the drilling mud instead of returning up the column is lost into unanticipated porous rock strata below casing level. There is a constant calculation of the "D" exponent or shale analysis made whilst drilling to provide warning that a geopressured or high pressure zone is in the vicinity below.

None of these occurrences in themselves mean that a blowout will occur, since in virtually all cases the problems are countered by measures such as increasing mud weight or closing in the well and circulating out gas cut mud. Problems of this nature are dealt with as a matter of drilling practice by standard procedures developed on the job and in special training schools. In cases where mud control cannot be maintained other safety measures are brought into play such as using the blowout preventors at the wellhead which will close off the well

by hydraulic rams and which if necessary, will cut through the drill pipe (should the pipe still be in the hole) in final emergency giving a complete seal.

Proportion of recorded blowouts between exploration drilling and development drilling for production operations is about 40% and 60% respectively, but this does not relate to the amount of oil spilled where generally the greater amount is from production blowouts. Blow-outs occurring during production operations are mostly due to accidents, such as the collision of a vessel with the platform, fires on the platform and platform failure or failure of other components. For an oil field of about 2 billion barrels (bbls) there is a 70% chance that at least one platform spill over 1,000 bbls will occur over the 20 year life of the field and for a field in the 500 million - 2 billion bbls size at least a 25% chance.

Primarily drilling blowouts are caused by human error, failure of equipment being one of the lesser causes. (Loss of oil to the oceans by offshore drilling and production operations amounts to approximately 1.6% of all spillage annually, although the massive spill from IXTOC 1 will certainly alter this estimate).

Preventive measures for all of these causes depend on stringent operational safety procedures both company and governmental, ensuring that structural design and equipment meet all safety requirements and that crews are fully trained and experienced. The Canada Oil and Gas Drilling Regulations enacted by the Department of Energy, Mines and Resources are among the most stringent in the world and departmental requirements for training and ongoing training of drilling personnel are comprehensive. Prior to commencement of any offshore drilling program or indeed before issuance of an authority to drill a well the operator must supply to EMR a comprehensive contingency plan covering response and environmental aspects which is discussed in detail with EPS, Coast Guard, the appropriate province and if necessary, Marcom.

Whilst the proposed drilling program and contingency plan are under scrutiny by EMR and other Federal and Provincial departments the detailed plan of the layout of the rig selected is also examined by EMR engineers. These engineers then travel to wherever in the world the rig is presently working, check it out and issue a list of the areas where they consider it falls short of Canadian standards. When the rig finally arrives in Canadian waters it is checked out again to ensure that the shortfalls have been rectified. During the drilling of the well, EMR inspecting engineers visit the rig at least every fortnight to check conduct of operations, provision of safety equipment, supply of heavy mud, etc. and also at such periods during the operation as may warrant further inspection.

Other requirements the Department of Energy, Mines and Resources insists upon is that before a drilling program is approved the operator must enter into an agreement with the Department for liability to the extent of $30 million, or more if so decided, for clean up costs in

the event of a spill and deliver an irrevocable letter of credit to the Minister to this effect.

In the event that it may be necessary to kill a wild well by a deviated hole an operator must demonstrate that:

a. other drilling units suitable for operation in the area at the appropriate time of year, and for the relevant water depth, exist within 20 days travel time of the area; and

b. a spare marine riser suitable for the relevant water depth and blowout preventer is available for use within 5 days.

The basic objective is that the operator be prepared under the most adverse circumstances to drill a relief well within 20 days.

When the contingency plan is submitted for an area where any possiblity of a spill reaching land is anticipated a spill trajectory analysis is conducted by dropping spill cards and plotting their course. When drilling has commenced a surprise oil spill exercise is conducted to involve both the operator and specific government departments.

Offshore reserves are estimated at about 25% of total proven reserves for the world as a whole and over 150 fields in 25 countries have been brought into production. Statistics from all areas are not available but some have been provided from the North Sea and the U.S. offshore which are of considerable interest to us.

More than 60% of recorded blowouts bridged, that is to say plugged themselves by collapse under the flowing forces from the oil bearing strata. This occurs within 5-20 days of commencement of the blowout, if it is going to occur. Blowout spills in the North Sea over 1,000 bbls. have averaged less than 2 per 1,000 wells drilled and currently over 1,600 wells have been drilled without additional spills from blowouts. On the Outer Continental Shelf of the U.S., 46 blowouts have occurred in the period 1971-78. Thirty of these occurred during drilling operations and the remaining 16 during completion, production and workover operations. During this period 7,553 new wells were started and one blowout occurred for every 250 wells drilled. This appears to be a high proportion but the American statistics list all spills over one bbl. Oil and condensate production over that period amounted to 2.8 billion bbls. and the total blowout spillage less than 1,000 bbls. But shortly after the period under discussion occurred the IXTOC 1 blowout in the Mexican sector dumping over 3 million bbls. (450,000 tons) into the ocean.

In the Canadian East Coast Sphere 172 wells have been drilled or are in drilling without mishap and this together with the U.S. and North Sea figures does, I think, point up the value of stringent government control of operations and insistence on the use of well trained personnel in lessening the chances of another IXTOC 1 where

these precautions were not so evident.

Oil deposited into the oceans annually varies between 4 and 6 million tons, of this approximately 32% comes from tanker mishaps and ships generally, 15% from natural seeps, 1½-3% from offshore oil and gas operations and 50% from non-marine operations. It is interesting to note that of this remaining 50% one half was accounted for by automative waste oil, although the value of this commodity has since been realized and collecting and re-processing systems are now in force.

Tanker Statistics and Pipelines

In the petroleum industry transport of hydrocarbon liquid causes the major amount of spillage in the oceans. Statistics vary but an estimate of about 30% of oil lost to the oceans each year would appear to have resulted from tanker spills or tanker related incidents.

Transhipment of hydrocarbon liquids from both Sable Island and Hibernia by tanker assuming a single buoy mooring is used poses three potential environmental hazards arising from:

a. the risk of spillage while making and breaking connections or due to hose rupture;

b. the hazard of tanker movements close to platforms and associated facilities; and

c. the problem involved in handling contaminated ballast water.

Improvements to single bouy mooring (SBM) operations to ensure flushing of hoses before disconnection, automatic system to ensure failsafe cut off, and hose improvements themselves have much reduced the potential for spillage. Similarly, it is most likely that tankers used in such a shuttle service will have bow loading equipment if subsea storage is used rather than have recourse to the older method of sideloading which will reduce the hazard of spillage and make for safer operating among oil field facilities.

One problem with such a shuttle service is that the operation known as "load on top" cannot be practised due to the short transit time. "Load on top" system is where oil in the tanker ballast water is allowed to separate during the ballast voyage permitting discharge of clean water at sea. The next cargo of oil is then loaded on top of the oil separated from the ballast water and the residual oily water. This will have to be dealt with by the handling and treatment of dirty ballast water or the use of separate ballast water tanks avoiding contact with the oil cargo. On platforms and loading terminals complex separation plants are installed which can remove all but a very small remnant of the oil from water, leaving a residue of less than 0.01%.

Storage of produced hydrocarbon liquids from the Sable Basin fields could be on the island itself - preferably in the area of the Western Spit where little ecological damage could result from an accidental condensate spill which would also then be localized. This I feel would be safer than offshore where a catastrophe involving floating or subsea storage could bring the condensate in a short time to the island over a long expanse of beach. Storage suitably surrounded by bunds on the island would pose less of a risk. A similar catastrophe at Hibernia would almost certainly direct the spill to mid ocean as indicated by the slick track analysis conducted for that area. Some 15 years ago a resolution was passed among major tanker operating countries that they would promote the idea that all tankers should be double hulled or have separate neoprene bags in each tank to minimize the chance of a spill but as far as I can ascertain it was never acted upon.

Compulsory pilotage and stringent monitoring of vessels and crew standards will serve to minimize chances of a severe tanker spill off Canada's east coast.

Pipelines

Since the proposal is to offload the Hibernia field by tanker, only the short gathering lines from the wellhead and the short lead line from the platform to the loading buoy are at hazard and as these will be well buried the risk of rupture is small. Failsafe valves will of course be incorporated in the system.

The major pipeline from Sable Island to the Canso area will transport gas only, stripped of gas liquids and dehydrated to acceptable sales standards of about seven pounds of water per million cubic feet to reduce risk, if any, of hydrate formation. Failsafe valves will again be used. As at Hibernia only a short lead line from either the platform or the island storage to the loading buoy would be at hazard. Here the risk is not ice but the sand waves which could alternately bury and undercut the line, but suitable burial or perhaps laying the line if fortuitiously possible, normal to the line of wave advance could minimize potential risk.

Offshore production spills and tanker spills are to some extent the antithesis of each other. In the case of a blowout we can determine where it will occur since we know the location of the well but we cannot with exactitude know the maximum quantity which will be lost to the ocean. We also know that it will be a gaseous crude or condensate with almost certainly an API gravity above 27° and so using the meagre variety of methods available of combatting an open ocean spill we can plan our remedial methods accordingly.

The maximum spill from a tanker can quickly be ascertained but its locality is difficult to predict in advance, although proximity to a heavily frequented port will naturally be considered a more vulnerable

area. The nature of the spill can run the gamut of the hydrocarbon chain from fuel oil to LNG although the fuel oil and dead crude (where full shrinkage has occurred) present the greatest challenge for remedial action.

Methods of combatting open sea spills in areas where the climate is as hostile as it is off our east coast are at best only partially effective.

It is dubious if any boom will work in 6 feet seas particularly with a confused breaking sea such as occurs at the edge of a spill. The periodicity of effective use of as skimmer as flotation moves it up and down through the oil water interface where it should be most beneficial is minimal in such seas. Absorbent batts would be a better proposition. Similarly for spraying dispersant I do not visualize spray booms and five barred gates attached to supply vessels as being the optimum method. In any sea 6 ft. or over the booms will be endangered even by the roll of the ship and are likely to be rendered useless. The area which can be sprayed by a ship is also small, except when extrapolated over a longer period of time. I believe we should concentrate on aerial spraying where large areas can be done speedily and in winds up to 50 mph and mobilization can be rapid. But here again airfields in the proximity are a prequisite and these are only now coming into being on the Labrador coast.

And so in some open ocean areas it is better to leave the spill to nature.

Future operations on the Canadian east coast must of necessity be considered by their respective areas since technical possibilities of production and the product itself varies by area so that the economic viability of production may be debatable.

Labrador Sea Area

We define this area as that lying between Belle Isle and Cape Chidley. The product to date has proved to be gas and the general geological opinion holds that if oil should occur in quantity it will be in the northern section of the area. The southern area will most likely be gas producing.

Exploration holes in this sector now cost $15 million upwards each and if production could be assured in the near future development wells would cost as much. From our knowledge of the porosity and permeability of the likely hydrocarbon producing zones it would require between 60 and 80 production wells per field to produce gas and probably over 100 to produce an oil field with an oil of say 34° API gravity. This would not include gas or water injection wells for secondary recovery. The assumption is that only production from "elephants" or a cluster of fields would be economic.

Labrador has a ria coastline with drowned river valleys persisting seaward which if occurring in the neighbourhood of the field would present the best possibilities for running a pipeline to shore. A trench is a prerequisite since iceberg scour has been mapped on the bottom with depression as deep as 30 feet and the possibility exists that these were originally up to 50 feet deep and have partially filled by slumping. An oil pipeline would consequently have to be buried in the regolith or bedrock if a glacial moraine or drowned valley were not fortuitously present in the vicinity of the field. A gas line would not be a potential pollution hazard since gas, although dangerous, is not a pollutant in the accepted sense of the term, and is only minutely soluble in sea water. However, it is unlikely that Federal or Provincial Environmental Departments would look kindly on such a line.

Seasonal production in the area, which we would interpret as 100 days from a floating platform, or a tethered leg platform offers a poor return financially and I would proffer the opinion that it is unlikely to be initiated.

The ultimate thoughts in production methods for the area could perhaps be an artifical island or subsea completions. The system presently used in Arctic waters of dredging and depositing seabed muck could not be used off Labrador. Nor the possibility of quarrying rock ashore and building such an island by free fall offshore. Water depths and distance from shore would necessitate a lead time of 10 years and generate a cost in excess of one billion dollars for such an island. The more logical system would be to build shallow barges after the style of the wartime bombardons which were used to form the mulberry harbours on the "D day" landing beaches. These could be built at a number of yards down the Canadian and U.S. east coasts, part filled with muck, towed to site, chained together in circular pattern and sunk. This would prove to be the fastest and cheapest method of island construction for year round production, or alternatively a modified "EKOFISK".

Subsea completions would have to be in silos cut out at least into the regolith if not into bedrock or protected by bunds. Although the iceberg drift is predominantly northwest to southeast a prolonged southeasterly gale of more than 3 day's duration can reverse this trend. Pipelines also would require trenching into bedrock or regolith or if feasible follow the trend of a drowned valley or moraine.

Summation of the above indicates that a viable economic oil production technology for the Labrador Sea does not yet exist. Gas could be produced but the distance from a sizeable market is so great that it is unlikely that this area would be developed whilst areas more fortuitously situated remain undeveloped.

But all of this is quite a way down the road.

Northern Grand Banks and Grand Banks Area

The northern Grand Banks area which we would define as that between Belle Isle and St. John's has to date been disappointing in its indication of hydrocarbon reserves and comment on the possibilities and hazards of production must be reserved until a more positive assessment has been realized.

Grand Banks Area

Possible production in the Grand Banks area is presently confined to the Hibernia field located in 270 feet of water about 168 nautical miles east of St. John's.

Environment factors which can most prejudice operations in the Hibernia area are sea ice and icebergs, the latter problem aggravated by fog, currents and highwaves; iceberg drift in the area can be 10 miles per day. The 100 year wave exceeds 75 feet and in winter significant waves over 8 feet occur 78% of the time; in summer 4% of the time.

Two possibilities in production methods are being considered, a floating production system and a fixed platform, the former being favoured. Transportation could be tanker or pipeline for either system but the tanker is preferred because of the distance to shore and also because pipelines could be susceptible to iceberg scour which in this area can be as deep as 30 feet.

A floating platform is less expensive, offers potential for relocation within the reservoir bounds and earlier production. By deviation platform wells can drain a large area particularly if subsea completions are also used to accommodate the configuration of the field and floating platforms can offer the bonus of easier maintenance in a shipyard if necessary. These outweigh the advantages of fixed platforms which offer more efficient production, less expensive wells and lower operating costs. But primarily the floating platform is safer as it can be quickly moved in the event of an approaching iceberg which cannot be towed or if sea ice in high concentrations and significant thickness approaches, the system can be temporarily moved to an ice free area.

The floating system would consist of a floating production platform, floating storage and tanker transport. Dynamic positioning is a possibility to enable the complex to move in the iceberg season. Well templates, each with about 10 wells, could individually be located in an excavation and the wells directionally drilled from a semi-submersible and the wellheads located below the seafloor. The number of well clusters producing to a platform would depend on well productivities and platform size.

Produced fluids would flow upwards to the platform through a

quick disconnect riser. After processing, the oil would flow down the riser and along the sea bottom then up through a single point mooring system to a storage vessel, probably ship shape and up to 1 million bbls. capacity. This technology is currently in effect in the Argyll and Buchan fields of the North Sea and off Brazil and Spain. Downtime is critical but it is anticipated that this would be less than 25%.

A 100,000 bbls/day system would probably be the minimum contemplated at first with 30+ wells at a cost of $1.3 billion 1980 dollars to develop about one half of the Hibernia field, not including shuttle tankers. If the oil is shipped to St. John's the tankers would probably not exceed 50,000 tons but if to Come by Chance, Canso or elsewhere with a deep harbour could exceed this. Time frame for initial production would be 5-7 years without political hindrance.

Slick track analyses conducted over this area indicate that an oil spill would probably move in a general southeasterly direction to the open ocean.

Scotian Shelf

Geological studies of the hydrocarbon provenance in the Scotian Shelf area have indicated that oil, in quantity, is unlikely, the probable product is gas with associated condensate.

Two fields at present have indications of possible commercial gas production being the Venture structure about 10 miles east of Sable Island and Thebaud about 4½ miles southwest of Sable. In proximity to the latter is the West Sable structure on Sable Island itself which could be produced in conduction with Thebaud. Gas-oil ratios of these Sable Basin fields vary from about 48,000 cubic feet/bbl. to 72,000 cubic feet bbl. indicating that these are true gas fields and liquid production would be ancillary.

The favoured method of production is by multiple deviated wells from fixed platforms since environmental dangers from ice are not a concern in this area. To produce Venture a minimum of two 20 well units plus injection wells would be required and for Thebaud it may be possible to produce from one 30 well unit plus injection wells. Deviation of each hole would probably not exceed 45° and from known permeabilities recoveries of up to 80% are considered feasible. Workovers on gas wells require some consideration because as the wells age and pressure drops, dewatering is a fairly frequent requirement.

Transport to shore would be by pipeline probably landing in the neighbourhood of Canso. If the requisite market can be established a production rate of 450 million cubic feet/day through a 30" line would be considered adequate for economic viability although initial start up would be about 250 million cubic feet/day. Assuming a gas-oil ratio average of 60,000, total condensate production from both fields would initially be about 4,000 bbls/day rising to about 7,500 bbls/day on

full stream. This would presumably go to floating storage at a loading buoy in safe location in the neighbourhood.

Chances of massive pollution from hydrocarbon activites in the Sable Island basin are low. The liquid production being condensate would be subject to rapid evaporation under the ambient atmospheric conditions of the area and the quantity produced is small. Natural gas itself is debatable as a pollutant, it is only marginally soluble in seawater and the possibility of hydrate formation is unlikely. The danger to personnel however is fundamentally obvious, particularly in conditions of temperature inversion. The result on ignition is an explosive flash resulting in 100% burns - there is nowhere to run.

Conclusion

Although oil has been produced from offshore facilities for over 50 years, the net impact to offshore fisheries appears to be minor. Concern has been expressed that equipment and rubbish jettisoned by rigs and supply boats could prove to be a serious concern to fishermen, but a rubbish harvest conducted by the Norwegian Government for the last year over the Viking Bank and Reef edge yielded 150 tons, 60 of which was from the oil industry and the rest from the fishing industry. It is conceivable, according to local belief, that snagged nets on the bottom of the Labrador Sea kill more fish, and will continue to do so since modern nets are not biodegradable, than any expected detritus from oil and gas operations.

There is evidence that the habitat and shelter created by the structure can attract fish and possibly increase productivity and survival. The loss of traditional fishing grounds and fishing gear appears to be negligible. Limited information on the effects on fishery resources of pipeline jetting, drilling muds and cuttings, oil leakage, brines and heavy metal contamination also indicates apparently minor impacts. The overall impression is that effects of offshore hydrocarbon production are small relative to other perturbations in the regimen of the fishing industry.

2. WHAT LEVELS OF OIL CONTAMINATION MAY BE EXPECTED IN WATER, SEDIMENTS AND WHAT WOULD BE THE PHYSIOLOGICAL CONSEQUENCES FOR BIOTA?

John Vandermeulen (DFO/OAS/MEL at BIO)

Potential petroleum exploration and eventual production involves three areas offshore from eastern Canada - the Grand Banks (HIBERNIA), Sable Island and George's Bank. Of these the Grand Banks and George's Bank promise crude oil, while Sable Island appears to contain primarily natural gas, with only a very minor oil component (Dexter, this report).

Possible impact of an oil spill, whether from a subsurface leak or blowout or from a surface spill, is of serious interest since all three areas represent important fishing grounds. Consequently the potential contamination of the water column and underlying bottom sediments and impact on the fishery becomes of enormous economic interest. This possibility will be discussed in this paper, with general focus on the Grand Banks/HIBERNIA situation, since it is sufficiently representative of the east coast shelf environment, even though there exist minor differences between it and the other major potential producing areas.

The paper is in three sections - firstly a discussion of oilspill movement and likely trajectory, secondly a discussion on the sorts of petroleum hydrocarbon levels that may be expected in the water and sediments of the Grand Banks, and lastly a discussion on the expected contamination of marine biota and the known effects on fish, plankton and macrobenthos. To illustrate various aspects of an offshore spill we will draw on experiences from two major spills - the 1976 ARGO MERCHANT Bunker C spill and the 1978 AMOCO CADIZ crude oil spill. Although dissimilar in several respects these spills have provided a better understanding of the way oil behaves at sea and how it comes in contact with the marine biota.

Spill Movement/Direction

Spill movement is dictated by two main factors - surface currents and wind - in addition to the effects of the Coriolis force and tidal movements. Surface current patterns for the Grand Banks are shown in Figure 1, with the principal current direction that of the Labrador current, from north to south. Over the Grand Banks proper the currents are relatively slower, while along the eastern edge, at the 200 m contour, the currents are more rapid.

Spill trajectories, calculated by month for oil released from the Hibernia site, suggest that the most probable direction of slick movement is southeast (Figure 2, Table 1). That is to say, out of 100 trajectories calculated the greatest number of trajectories lead in a southeasterly direction from the well site. However, it should be noted that for nearly every month there are certain probabilities of trajectories for the other compass points. In fact, it is especially

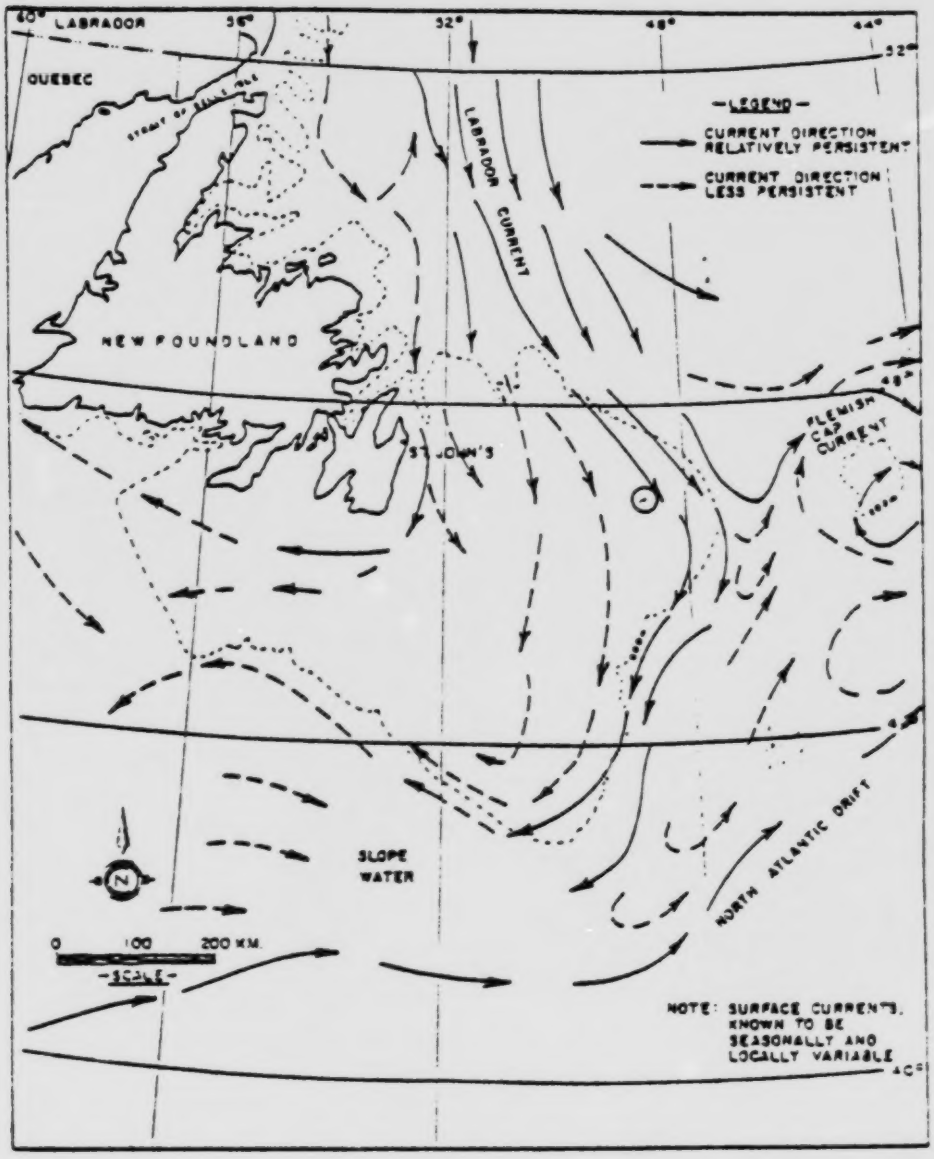
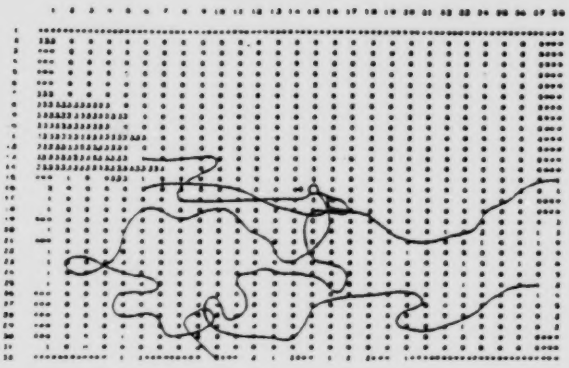


FIGURE 1. Major surface currents in Grand Banks area (Mobil-HIBERNIA, 1979).

ENDPOINT DISTRIBUTION FOR 100 ITERATIONS
START TIME (M.D.HR)= 5 1 1200 ALPHA= 0.035 CORIOLIS ANGLE= 20. CURRENT MULTIPLIER= 1.0



START:	May 1, 1979
PERSISTENCY:	mean ± σ
SPEED:	mean ± σ
% ENDPOINTS ON SHORE:	8
% ENDPOINTS EAST BOUNDARY:	52
% ENDPOINTS SOUTH BOUNDARY:	16
% ENDPOINTS WEST BOUNDARY:	10
% ENDPOINTS NORTH BOUNDARY:	-
% ENDPOINTS INTERNAL:	14
EARLIEST TIME ON SHORE (DAYS):	19
MOST PROBABLE DIRECTION:	SE

FIGURE 2. Sample spill trajectory for HIBERNIA. Table shows percentage probabilities for different end-points. (Mobil Hibernia-35, 1979).

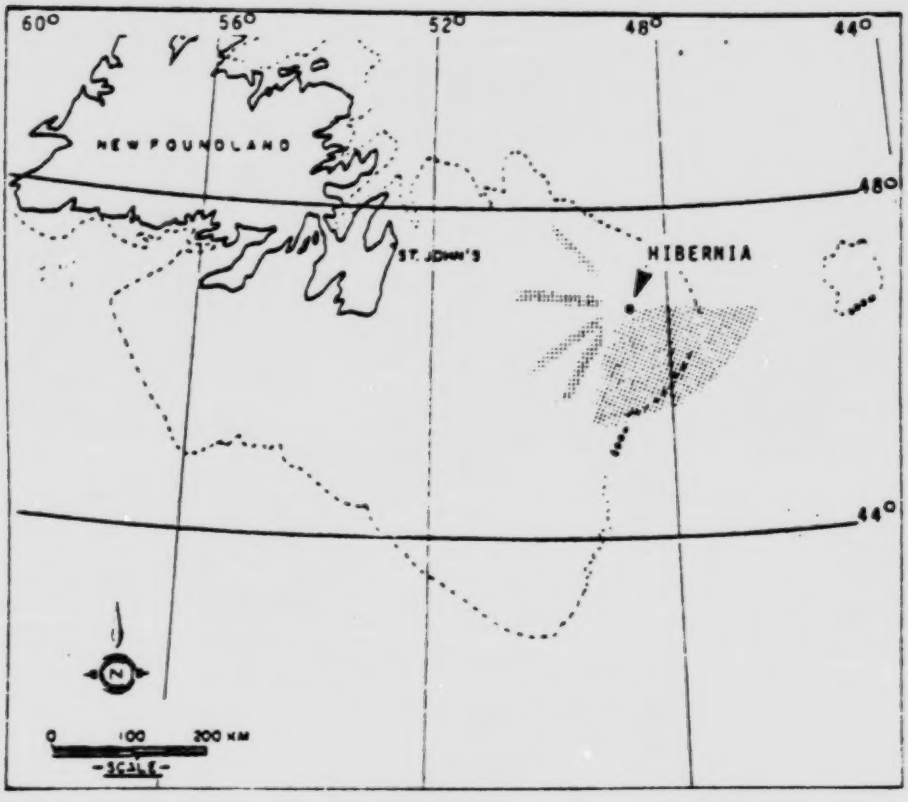


FIGURE 3. Most probable spill directions originating from HIBERNIA. (after Mobil HIBERNIA-35, 1979).

TABLE 1. HIBERNIA spill scenarios developed for 100 iterations. (After Mobil Hibernia-35 Spill Contingency Plan, part B)

Month	Shore	East	South	West	North	most probable dir'n	Internal
November	2	91	4	3	-	SE	-
*	9	63	19	8	1	SE	-
*	2	89	7	-	-	SE	2
*	-	99	1	-	-	SE	-
December	-	82	9	1	-	SE	8
January	2	41	46	9	-	S to E	2
February	8	60	20	6	1	SE	5
*	9	52	30	3	4	S to E	2
*	13	49	20	4	1	SE	13
*	11	80	5	1	-	SE	3
March	7	53	25	14	-	SE	1
April	2	42	38	7	-	S to SE	11
May	8	52	16	10	-	SE	14

* Factors for current and persistence variation added in.
All others based on seasonal constancy of current and wind only.

TABLE 2A Hydrocarbon concentrations commonly found in oceanic waters (from Boehm et al, 1978).

Location	Concentration (µg/l) (ppb)	Comments	Reference
Georges Bank Region	0.2-98	Gas Chromatography (GC)	This study
South Texas OCS	0.1-2.0	Paraffins only	Barryhill (1977)
Alaska OCS		GC	Shaw (1977)
Gulf of Mexico Loop Current	0-75	GC	Iliffe & Calder (1974)
West African Coast	10-65	GC	Barber et al. (1973)
French Coast	46-137	GC	Barber et al. (1973)
Open Ocean (Atlantic)	1-60	IR	Brown et al. (1973)
	<8	Fluorescence	Gordon et al. (1974)
	20	1-3 mm Fluorescence	Gordon et al. (1974)
Mediterranean Sea	2-200	Surface (IR)	Brown et al. (1975)
	2-8	Subsurface (IR)	Brown et al. (1975)
Atlantic	0.5-6		Brown et al. (1975)
Baltic Sea	50-60	Non-aromatics	Zsolnay (1972)
Gulf of Mexico (coastal)	1-8	n-alkanes only	Parker et al. (1972)
Galveston Bay area	8		Brown et al. (1973)
New York Bight	1-21		Brown et al. (1973)
Gulf of Venezuela	50		Brown et al. (1973)
Bedford Basin, Nova Scotia	1-80		Kaiser & Gordon (1973)
Gulf of St. Lawrence	1-15		Levy & Walton (1973)
Narragansett Bay	8.5	GC	Duce et al. (1972)
	8-15	GC	Boehm (1977)
Woods Hole Harbor	11	GC	Stegmann & Tsai (1973)

interesting to note that for all months there are a number of internal trajectories, i.e. cases where the oilslick would not leave the Hibernia/Grand Banks area, but would remain in the vicinity of the release point.

One point that is often underestimated, and is often lost sight of in trajectory calculations based on averages or mean winds, etc., is the unexpected mobility of a surface slick over a brief period. In fact, a brief but violent storm can easily over-ride the sort of surface currents found on the Grand Banks, with a surface slick travelling a very great distance over a short period of time. While these conditions are normally averaged out of the calculations, it must be realized that a strong consistent two or three day wind can drive a surface slick several hundred kilometers in an unexpected direction.

While so far we have been discussing surface slicks per se we can reasonably treat a potential blowout or subsurface spill in this same discussion. The depth of water over the Grand Banks is shallow enough that most, if not all, of the oil erupting from a blowout will reach the surface. Some of the oil, in the form of droplets created at the mouth of the blowout, will become entrained in the water column for some time (Figure 4), but depending on the size they will in time also reach the surface. Calculations made for Mobil Oil suggest that the smallest of these, 50 μm and smaller, may surface some 10 km downstream from the blowout site (Mobil et al., 1979). This downstream movement by oil droplets may well be greater, as suggested by observations of Forrester (1971) who tracked ARROW oil droplets several hundred kilometers away from the ARROW site, some as far as Halifax. Thus, while a subsurface break or blowout in general can be treated as a surface slick, for the purpose of our considerations, there can be a significant sub-surface component in the form of oil droplets being carried a considerable distance. This aspect becomes important in our later discussion of their availability to filter-feeding organisms as zooplankton.

Spreading of a uniform surface slick has been modelled in Figure 6, which shows the increase of both and central thick portion of the slick and that of the overall slick area. An interesting by-product of the surface slick is the cloud of dispersed oil under the slick, spreading correspondingly, and constantly entering the water column by dispersion and dissolution. Based on dye-diffusion studies the diameter of the water-born oil cloud under the slick at first is smaller than the slick itself. Within 24 hours, however, according to these simulation studies the growth of the diffusion cloud (scale of diffusion) exceeds that of the surface slick (MacKay and Leinonen, 1977). (One of the main factors dictating these differences in spreading is the surface tension at the surface). This spreading of the sub-surface oil cloud is of great significance since it will effect both the potential hydrocarbon concentrations in the water column, but more importantly the bioavailability of the oil to pelagic and planktonic biota.

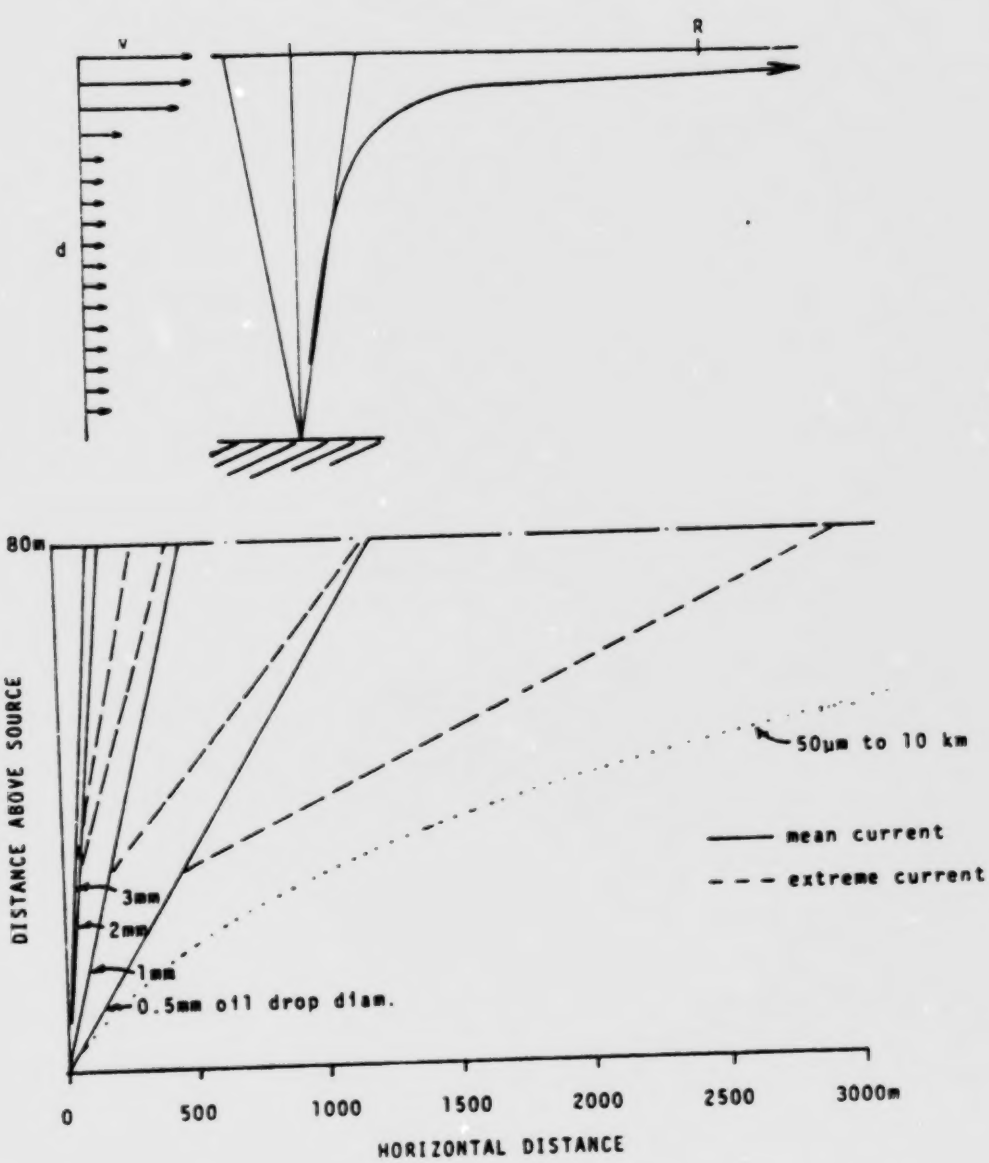


FIGURE 4. Schematic representation of blow-out and movement of resulting oil-flow. Lower figure shows path of oil droplets. (v = current velocity, d = depth, R = wave ring around blow-out plume.) (After Mobil-HIBERNIA 1979).

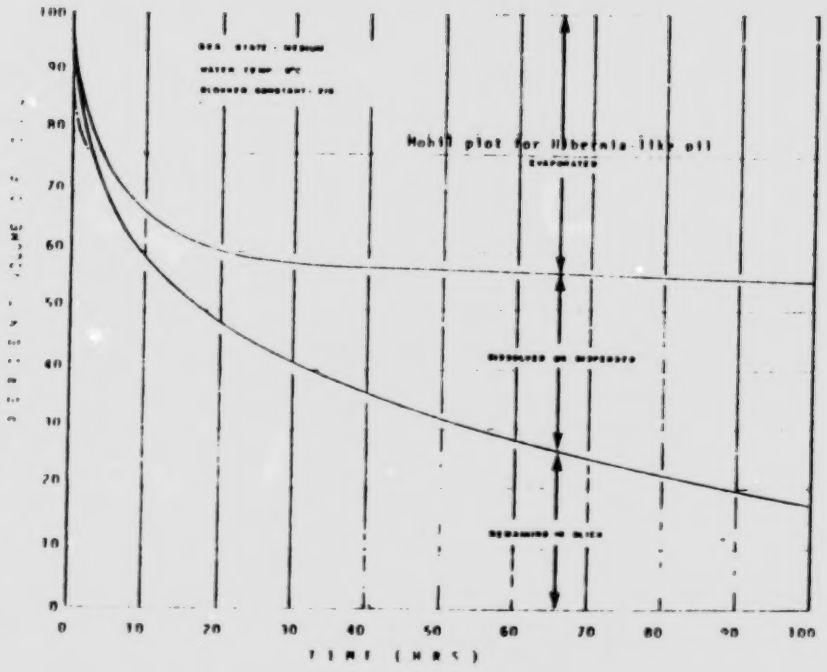


FIGURE 5. Schematic model of fate of oil spilled on water. (After MacKay & Leinonen, 1977). Dashed line shows evaporation curve for HIBERNIA crude oil (from Mobil-HIBERNIA, 1979)

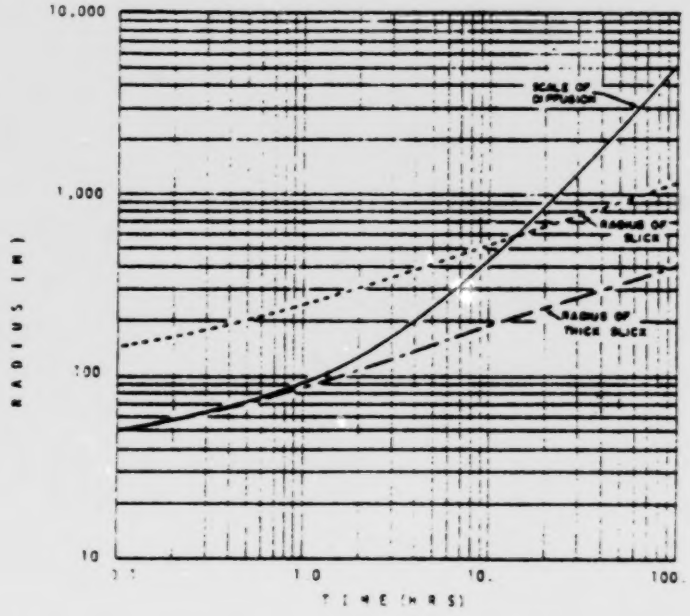


FIGURE 6. Spreading behavior of slick and sub-surface oil-in-water cloud (scale of diffusion). Thick slick radius is that of central thicker region of surface slick. (MacKay & Leinonen, 1977)

In summary, the most probable or most likely direction of slick movement, originating from the HIBERNIA site, is in a general south-easterly direction, with a strong easterly component. However, there is a likelihood that a slick may remain in the area for some extended time, before drifting off the banks. As well slicks are highly mobile, and under the driving force of strong winds can drift long distances in an unexpectedly short time period.

A surface slick is accompanied by a sub-surface cloud of oil accommodated in the water column by dispersion and dissolution. Initially the area of the surface slick exceeds that of the sub-surface scale of diffusion. Simulation studies suggest, however, that within a few days the radius of the sub-surface diffusion area exceeds that of the surface slick. Thus where at the surface only one area is affected, sub-surface a far greater area becomes contaminated.

Hydrocarbon Concentrations in Water and Sediments

Factors affecting diffusion - A simplified scheme for the fate of oil spilled on water is shown in Figure 5. The main factors affecting the fate of spilled oil are evaporation, dispersion, dissolution, photooxidation and biodegradation (including ingestion and microbial). Of these various processes evaporation and dispersion/dissolution play the main roles during the first days of the spill. Photooxidation is a lesser and much more poorly understood factor. In the long-term biodegradation takes on an increasingly important role, but is a negligible factor during the first days or weeks of the spill incident.

Evaporation can account for the loss of up to 40 or 50% of the spilled oil within the first 24 hours, for example the loss estimated for the ARGO MERCHANT (Grose and Mattson, 1977). This of course is dependent on the type of oil spilled. For Hibernia oil a loss of around 23% has been calculated to occur within the first five or six hours (dashed line, Figure 5; Mobil et al., 1979). The portion of oil lost by evaporation consists largely of the lighter fractions, the light ends up to C_{13} including some of the napthalenes (smaller aromatics). Thus the oil remaining in the surface slick, after 24 or 48 hour evaporation, will have changed materially from the original spilled oil, having fewer of the lighter, more volatile, components.

The oil entering the water column enters by two processes - dispersion and dissolution. Of these dissolution is much the less factor, accounting for only up to around 10 to 30 ppb (Figure 7). Dissolution is a function only of the solubility coefficient of the molecular species involved (Clark and Brown, 1977). By far the most important is dispersion, by which oil as oil droplets becomes entrained in the water column as a result of vigorous physical mixing. Short-term concentrations exceeding 1 ppm have been measured, although

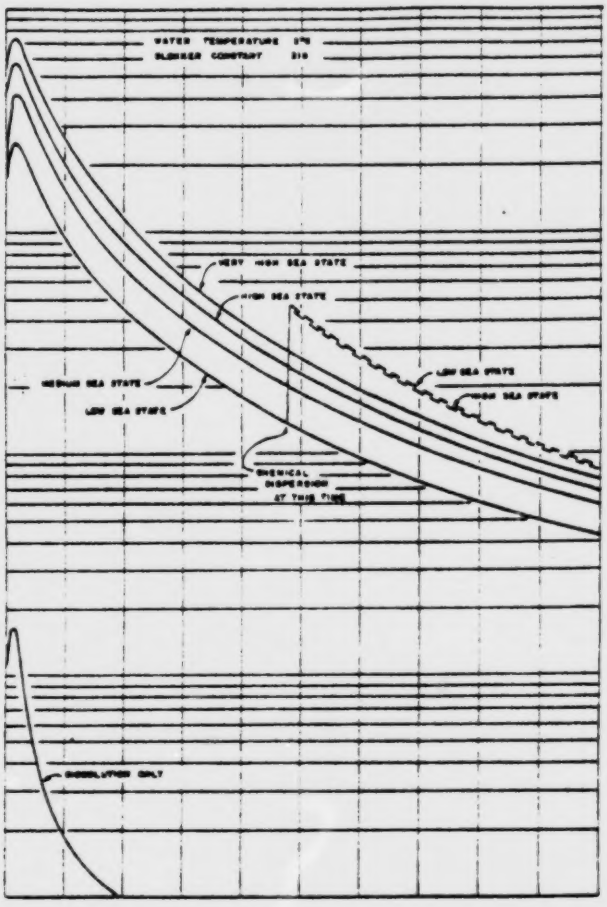


FIGURE 7. Concentration of dissolved and dispersed (physical and chemical) hydrocarbons vs. time. (MacKay & Leinonen, 1977).

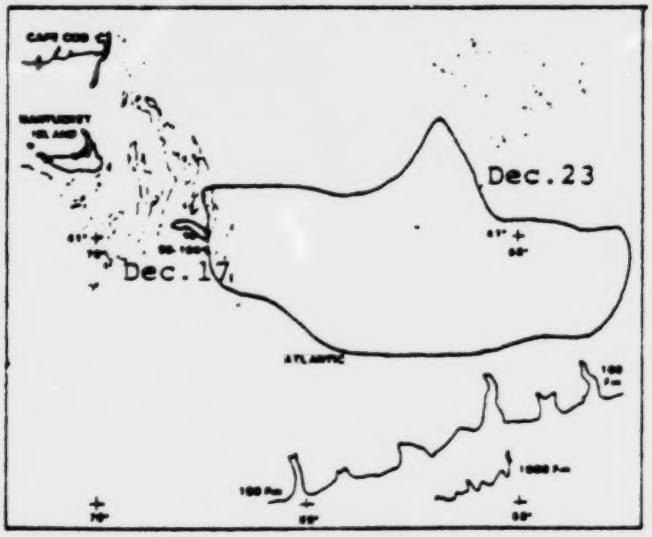


FIGURE 8. Location and extent of ARGO MERCHANT oil slick, Dec. 17 and Dec. 23 1976. (Hoffman & Quinn, 1978).

more usually hydrocarbon concentrations by dispersion are in the order of 100 to 300 ppb. Thus hydrocarbon concentrations several orders of magnitude greater than would be expected from solubility coefficients alone can be readily achieved, and in fact are achieved under spill conditions.

It is important to note that unlike the surface slick, which will have lost its light toxic ends by evaporation, the dispersed oil will still contain these lighter ends to some extent since they escaped evaporation. These lighter ends are also readily soluble and in general highly toxic. The toxic events then within the water column are quite different from those going on at the surface. In fact, it is highly probable that the massive mortalities of benthic bivalves and heart-urchins observed followed the AMOCO CADIZ spill in north Brittany (e.g. Hess, 1978) were due to the persistence of the light toxic components of the crude oil carried into the water column by dispersion.

Typical concentrations of petroleum hydrocarbons measured in various oceanic waters are listed in Table 2A, some from oiled or polluted waters and others from non-polluted offshore waters. Although measured by different methods the values given are generally indicative of the levels one can expect. Typical background levels for offshore sources are in the low 0.1 to 10 ppb range, while higher values (10-75 ppb) are found in more coastal or inshore waters. Levels may reach 100 and 200 ppb in known polluted waters (e.g. the Mediterranean). All waters appear to contain some contaminant hydrocarbons in the surface film, although much lower concentrations are found at depth (Table 2B).

Case Histories: ARGO MERCHANT AND AMOCO CADIZ

Water column - The breakup of the ARGO MERCHANT (December 15, 1976) 29 nautical miles southeast of Nantucket Island, Massachusetts, spilled 7,7000,000 tons of No. 6 fuel oil (Bunker C) into the north Atlantic waters. Fortunately winds were offshore for the duration of the spill and the resulting oilslick was driven offshore into deeper waters, and eventually lost from sight (Figure 8).

Hydrocarbon concentrations in the water column at the time of the spill exceeded 200 ppb near the surface, and were over 200 ppb down to 20 meters (Table 3). Presumably these high levels were the result of dispersion of the Bunker oil into the water column, a function of the high seastate at the time of the spill. Subsequent resampling showed that within two months concentrations had decreased to ca. 20 ppb, and by mid February 1977 near background levels, around 10 ppb, were found in some samples.

Table 2B. Depth distribution of hydrocarbons (McAuliffe, 1976).

	depth(m)	#	(ug/l)
N W Atlantic Nova Scotia to Bermuda, Gordon et al. (1974)	0-3 mm	43	20.4 + 60.7
	1	24	0.8 ± 1.3
	5	24	0.4 ± 0.5
	>5	?	0.0
Gordon and Keizer (1974)	1-5 mm	53	9.3 ± 18
	1	23	0.6 ± 0.6
	5	24	0.4 ± 0.4
	10-1000	50	0.0
Atlantic — Sargasso Sea, Wade and Quinn (1975)	0.1-0.3 mm	17	155 ± 149
	0.2-0.3	17	73 ± 58

Table 3. Hydrocarbon concentrations in seawater under spill conditions (ARGO MERCHANT, Boehm et al, 1978; TSESIS, Kineman & Clark, 1980).

ARGO MERCHANT, 1976.
7,700,000 gal's Bunker C

	Dec.'76	Jan/Feb.'77	mid-Feb.'77	May'77	Aug'77
surface	up to 310 ppb				
3 m.	" 340	ca. 20 ppb	10-99 ppb	1-49 ppb	0.3ppb
10 m.	" 270				
20 m.	" 210				

TSESIS, 1977.
400 Tons #5 & #6.
2-5 d weathered oil (mousse), low mixing energy

0.5 m	50.9 ug/l
1.0 m	58.2 "

It is interesting to compare these measurements with those obtained under a weathered similar oil (viz. Table 3 "TSESIS spill"). Concentrations in that case were in the 50 ppb range, which, although elevated and indicating hydrocarbon contamination, were quite a bit lower than for the ARGO MERCHANT. These figures fit our understanding of slick behavior at sea, however, in that they were obtained under a well-weathered (evaporated) slick in an area of low-mixing energy, all factors which would ensure a lowered dispersion.

The AMOCO CADIZ spill differed from the ARGO MERCHANT* spill in several aspects. The grounding and breakup of this supertanker (March 1978) off the western tip of north Brittany resulted in a spill of 220,000 tons of a mixture of two light mid-eastern crude oils. In time, with the aid of shifting winds oil slicks covered the entire portion of the English Channel between the north Brittany coast line and the island of Guernsey (Figure 9).

Water column hydrocarbon concentrations measured between March 30 and April 4 (two weeks after the spill) showed a range of contamination (Table 4). Some stations had elevated values (e.g. #1, 3, 5, 6, 23, 29) while near usual background levels were found in the offshore stations (14 - 20, 32 - 36). It is interesting to note that in several stations a marked decrease had occurred by the time the stations were resampled on the return leg of the cruise (e.g. #1 and 37, 2 and 38, 3 and 39).

An unexpected aspect of the AMOCO CADIZ spill, however, was the near uniform contamination of the water column, with high petroleum hydrocarbon levels measured the full depth of the stations, down to 70 and 100 meters (Table 5). This phenomenon had not been observed before, and was totally in contrast to the more usual pollution picture seen earlier (Table 2B) and what has been found during a spill of Bunker C off Greenland (Figure 10). In the latter a gradient of hydrocarbon concentrations was determined, with higher levels found in the top meter, but with background levels found at depth.

Even in these cases of complete water column contamination, however, hydrocarbon levels returned to near background shortly (Tables 6 and 7).

* Bunker C oil contains the highest boiling fraction of the heavy distillates from crude oil. As well a "cutter stock" consisting of lower boiling lower molecular weight compounds is added. For all intents and purposes a weathered crude oil soon takes on the physical characteristics and behaviour of a Bunker type oil (Levy, personal communication).

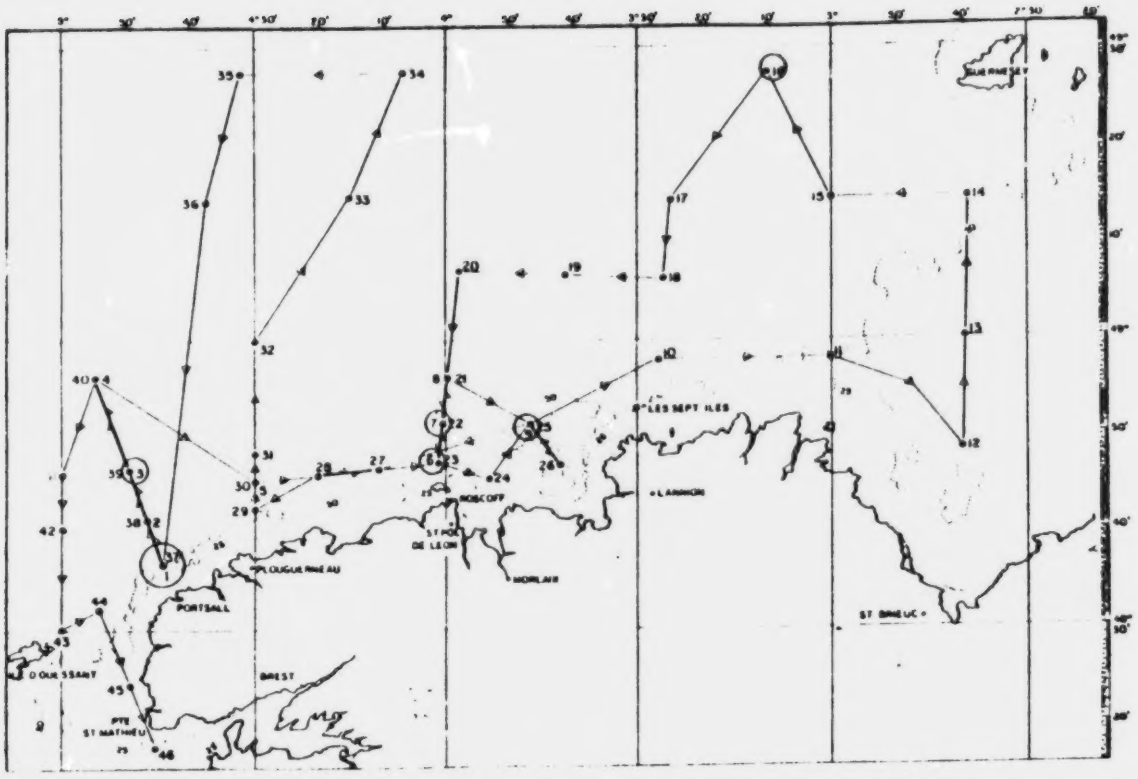


FIGURE 9. Offshore sampling stations, Suroit cruise March 30 - April 4, 1978 following AMOCO CADIZ spill. Circled stations are reported in Table 5.

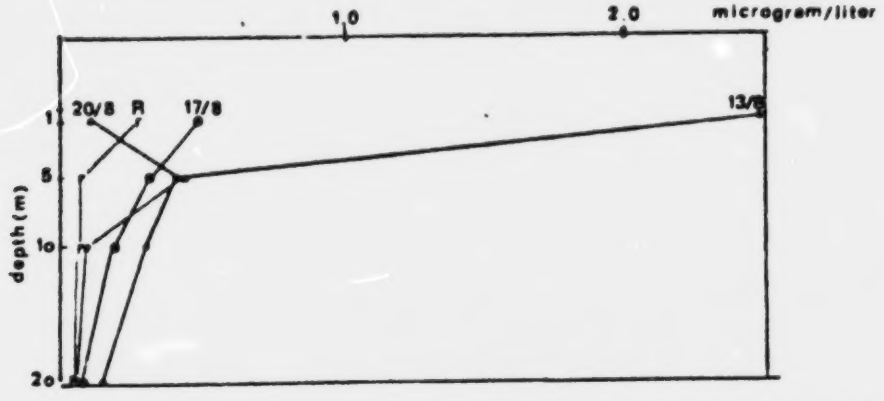


FIGURE 10. Petroleum hydrocarbons in subsurface water samples following USNS POTOMAC spill, 1977, Melville Bay, Greenland. (380 T Bunker C). (Pedersen, 1978).

TABLE 4 . Total hydrocarbon concentrations in seawater surface layer (1 m sampling depth) in the English Channel, Mar.30 to Apr. 4 '78. (Marchand, 1978).

Date	Localisation	N° de station	Position		Sonde (mètres)	Hydrocarbures totaux (µg/l)
			LAT (N)	LONG (W)		
30/3		1	48°37'	04°42'5	44	138,0
	Radiale N.W. face à Portsall	2	48°41'1	04°45'6	100	11,7
		3	48°45'6	04°49'2	100	14,3
31/3		4	48°56'	04°54'5	100	5,2
		5	48°44'8	04°30	98	16,6
		6	48°46'6	04°00'7	45	46,4
	Radiale face à Roscoff	7	48°49'2	03°57'7	75	15,6
		8	48°54'	03°58'	80	9,1
		9	48°52'5	03°49'3	75	17,9
	Des "Triagoz" à la baie de St-Brieuc	10	48°57'	03°25'8	65	9,1
		11	48°57'9	02°59'6		3,9
1/4		12	48°48'1	02°40'1		2,9
	Radiale face à St-Brieuc	13	49°00'3	02°40'		7,6
		14	49°14'	02°40'2		0,9
		15	49°14'5	03°00'	70	3,6
		16	49°27'4	03°10	70	1,0
	Zone au large	17	49°14'3	03°24'5		0,9
		18	49°06'5	03°25'3	75	2,9
2/4		19	49°07'2	03°40'5	80	2,1
		20	49°07'3	03°57'4		4,3
		21	48°56'2	03°59'5		3,5
	Radiale face à Roscoff	22	48°51'2	04°01'	80	9,4
		23	48°47'2	04°01'1		19,2
		24	48°45'5	03°52'1		8,8
	Baies de Morlaix et de Lannion	25	48°51'5	03°46'3	70	5,5
		26	48°46'7	03°42'2	49	12,3
		27	48°46'3	04°11'4		3,2
		28	48°45'9	04°20'7		6,1
		29	48°42'7	04°30'		26,8
		30	48°45'1	04°30'	90	10,2
	Radiale face à Plouguerneau	31	48°48'4	04°29'8	90	18,9
3/4		32	49°00'	04°29'8	100	1,8
		33	49°15'	04°14'5	94	3,2
		34	49°27'4	04°06'8	90	1,3
		35	49°27'6	04°31'9	90	0,8
	Radiale face à Portsall	36	49°15'1	04°35'1	90	2,1
		37	48°37'	04°42'5		1,5
		38	48°41'5	04°46'5		2,1
	Radiale face à Portsall	39	48°45'5	04°53'5		2,7
		40	48°56'5	04°55'1		1,7
4/4		41	48°46'1	04°59'8	110	non prélevé
		42	48°40'5	05°00'		1,0
	Radiale face à Ouessant, Chenal du Four	43	48°29'7	05°01'7	85	1,0
		44	48°32'	04°54'	45	0,6
		45	48°24'5	04°48'8		non analysé
		46	48°17'6	04°46'5	32	1,8

TABLE 5. Total hydrocarbons (ug/l) in the water column for selected near-shore and offshore stations (March/April 1978) (Marchand, 1978) For station numbers see Figure 9.

Station : 1		Station : 3		Station : 6	
Profondeur (m)	Hydrocarbures (µg/l)	Profondeur (m)	Hydrocarbures (µg/l)	Profondeur (m)	Hydrocarbures (µg/l)
1	138,0 (*)	1	14,3	1	46,4
1	136,1 (**)	2	19,7	2	36,4
5	152,9	5	19,9	5	38,6
20	84,1	20	18,6	20	51,1
44	102,7	100	42,3	40	27,7
Station : 7		**Station : 9**		**Station : 16**	
Profondeur (m)	Hydrocarbures (µg/l)	Profondeur (m)	Hydrocarbures (µg/l)	Profondeur (m)	Hydrocarbures (µg/l)
1	15,6	1	17,9	1	1,0
2	9,9	2	8,3	2	0,6
5	12,1	5	13,8	20	1,1
20	16,6	20	19,8		
70	18,3	70	19,6		

TABLE 6. Loss of hydrocarbons in seawater samples between end of March and mid-April 1978. (Marchand, 1978).

Zone	Campagne	Station	Date de prélèvement	Hydrocarbures totaux (µg/l)
Ile Vierge	SUROIT 1	29	3/4	26,8
Plouguerneau	THALIA	18	18/4	4,6
Ile de Batz	SUROIT 1	6	31/3	46,4
Roscoff	SUROIT 1	23	2/4	19,2
	THALIA	17	18/4	8,4
Baie de Morlaix	SUROIT 1	24	2/4	8,8
	THALIA	7	16/4	8,5
Baie de Lannion	SUROIT 1	26	2/4	12,3
	TTHALIA	8	16/4	9,1
	THALIA	9	16/4	8,8

Sediments - Sediment analyses immediately following the breakup of the ARGO MERCHANT showed a fair amount of oil in the immediate vicinity of the tanker wreck, with further moderate but general contamination throughout the area (Grose and Mattson, 1977, p. 85). It was concluded that much of this sediment oiling was probably not derived from the surface oilslicks, but came from the hull section directly as the sunken bow drifted along the bottom toward deeper waters. The more general but lesser contamination of the surrounding sandy sediments was quite reasonably thought to have been the result of sand movements in the area carrying the oil outward over the bottom sediments. Certainly by the following February, two months later, bottom sediments appeared to be relatively clear of contamination, except in areas immediately near to the wreck site (Figure 11, Table 8).

A comparable analysis of bottom sediments for the AMOCO CADIZ case presents quite a different picture, with petroleum hydrocarbons persisting for over a year after the spill. Ten weeks after the spill residual hydrocarbons were found in a number of stations, primarily in inshore stations with highest levels in the bays of Morlaix and Lannion (Figure 12, Table 9). A subsequent detailed sampling program carried out by Cabioch and co-workers out of the University of Paris marine laboratory at Roscoff showed a concentration of petroleum hydrocarbons in areas of soft sediments (Figure 13A), with a subsequent increase in concentrations over the following year (Figure 13B). It would appear that petroleum hydrocarbons caught up in soft benthic sediments can in fact migrate to areas of lower-energy fine sediment deposits.

Relevance to the eastern Canada offshore - The ARGO MERCHANT and the AMOCO CADIZ are two distinctly different spill situations, and certainly at first glance the AMOCO CADIZ spill seems less relevant to the Grand Banks/HIBERNIA situation. HIBERNIA is offshore, with the entire Atlantic ocean downstream from it. The AMOCO CADIZ was essentially an onshore spill, with a very large amount of oil being contained in that parcel of the English Channel by the north Brittany coastline. On the other hand the ARGO MERCHANT was offshore, in similar depths of water, and seems to fit the HIBERNIA scenario much better.

So why use the AMOCO CADIZ as a comparison spill? Simply because the HIBERNIA scenario contains aspects of both these. It is very likely that with the right winds and the southerly currents a Grand Banks spill will drift off the banks into the open ocean. But HIBERNIA spill trajectory calculations also indicate a certain probability that a slick may remain in the area and not move off into the Atlantic until after some length of time (the internal trajectory). Then the HIBERNIA takes on some of the features of the AMOCO CADIZ - oil slicks

TABLE 7. Hydrocarbon levels in water samples (AMOCO CADIZ) collected two to four days apart at the same stations. (Marchand, 1978).

Zone	Station	Date de prélèvement	Hydrocarbures totaux (µg/l)
Radiale N.W. face à Portsall	1	30/3	138,0
	37	3/4	1,5
	2	30/3	11,7
	38	3/4	2,1
	3	30/3	14,3
	39	3/4	2,7
	4	30/3	5,2
	40	3/4	1,7
Radiale N. face à Roscoff	6	31/3	46,4
	23	2/4	19,2
	7	31/3	15,6
	22	2/4	9,4
	8	31/3	9,1
	21	2/4	3,5
Plateau des Triagoz	9	31/3	17,9
	25	2/4	5,5

TABLE 8. Sediment hydrocarbons (ARGO MERCHANT), Feb. '77. For station locations see Figure 8.

Station (replicate)	*Depth of sediment (cm)*	*Total hydrocarbons µg/gm (dry wt sediment)*	*Station (replicate)*	*Depth of sediment (cm)*	*Total hydrocarbons µg/gm (dry wt sediment)*
50(1) G*	0-1	<0 1	59(2) BC	0-4	0 3
50(2) G	0-1	0 8	59(2) BC	4-9	0 8
50(2) G	1-3	0 4	59(2) BC	9-14	0 4
50(2) G	3-5	<0.1			
			61(2) G	0-1	1 1
56(1) G	0-1	1 2	61(3) G	0-1	0.7
56(3) G	0-1	<0.3			
56(4) G	0-1	21 5	70(1) G	0-1	12 8
			70(1) G	1-3	29 6
57(1) G	0-1	<0 1	70(1) G	3-5	11 5
			70(1) G	>5	19.7
59(1) G	0-1	2 4†			
59(1) G	1-3	0 5	70(3) G	0-1	10 2
59(1) G	3-5	<0 1†	70(3) G	1-3	4 0
			70(3) G	3-5	5 6†
59(3) G	0-1	2 8†			
59(3) G	1-3	<0 1	70(4) G	0-1	118. 69 7. 35 7††
59(3) G	3-5	<0 1	70(4) G	1-3	5 1
			70(4) G	3-5	122
59(4) G	0-1	0 3			
59(4) G	1-3	0 1	70(1) BC	0-3	1 9
59(4) G	3-5	<0 1	70(1) BC	3-8	2.7
			70(1) BC	8-13	2 2
59(1) BC*	0-3	5 1			
59(1) BC	3-8	1 3	70(2) BC	0-3	2 7
59(1) BC	8-13	24 6	70(2) BC	3-8	28 2
			70(2),BC	8-13	37 5

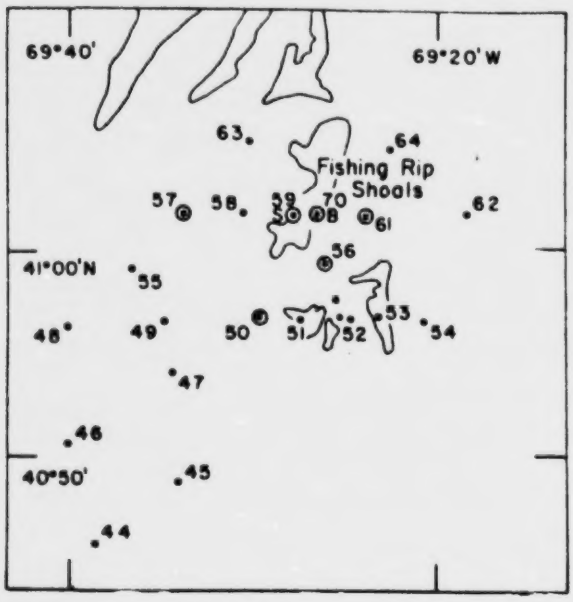


FIGURE 11. Station locations for sediment samples taken after ARGO MERCHANT oil spill (viz. table 8 this report). Original wreck site = #59. Circled stations are those with reported oiled sediments. (Hoffman & Quinn, 1978).

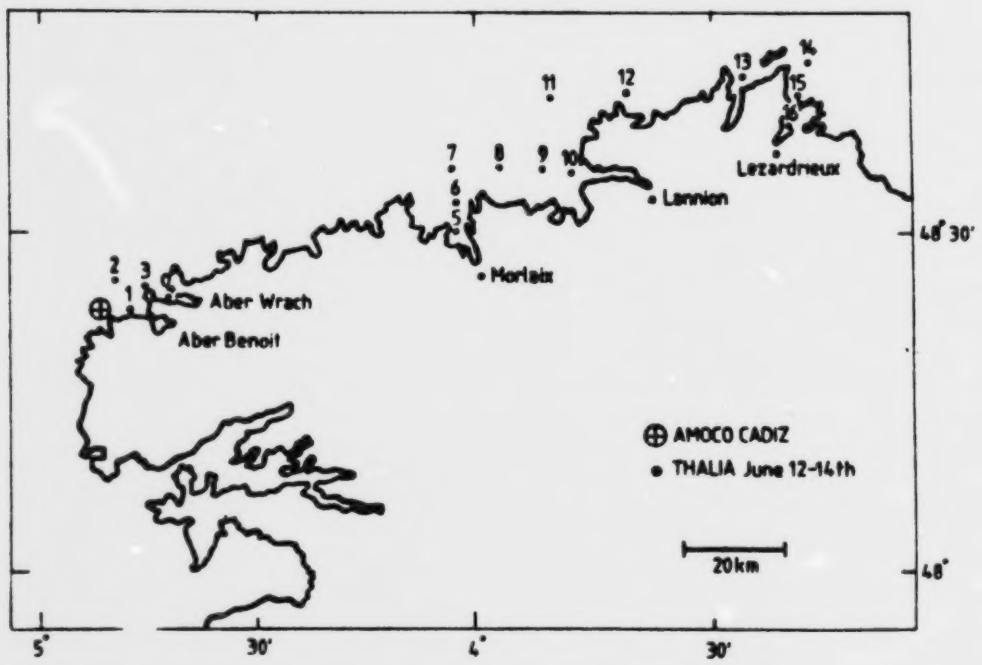


FIGURE 12. Sampling station locations for sediment samples collected 12-14 June 1978 following March 1978 AMOCO CADIZ wreck. For sediment analyses viz. table 9.

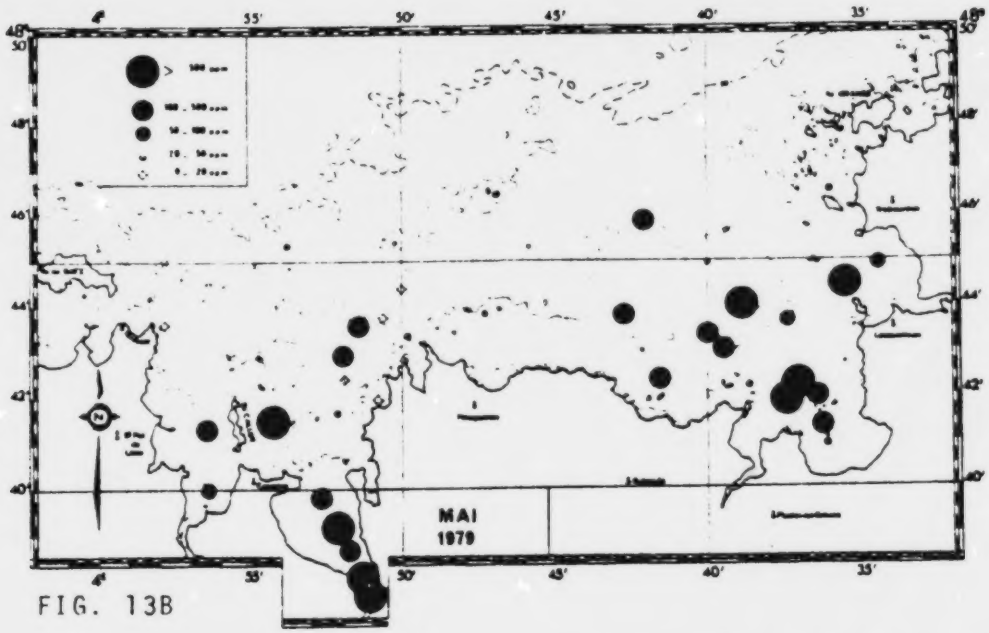


FIG. 13B

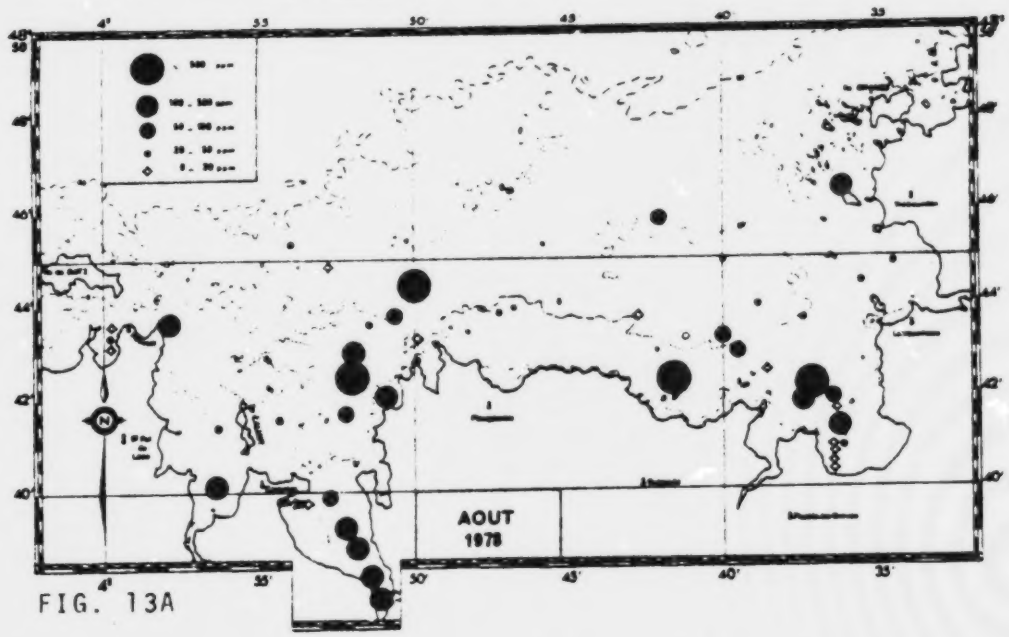


FIG. 13A

FIGURE 13. Redistribution of bottom sediment petroleum hydrocarbons, August 1978 to May 1979, following oiling by the AMOCO CADIZ. (Besslier et al, 1980).

persisting on the Grand Banks, similar water depths with potential mixing throughout the water column, hydrocarbon penetration into the water column and the likelihood of bottom sediment contamination. This also means a different degree of impact on offshore stocks and benthos.

Certainly, one worst case scenario for the HIBERNIA involves the total loss of the contents of an offshore storage facility, possibly as much as 160,000 tons (Dexter, personal communication). Such an amount equals that of a supertanker spill, as the AMOCO CADIZ (ca. 220,000 tons). A spill of that magnitude would cover a significant portion of the Grand Banks (Figure 14), perhaps as much as eight or ten percent of the banks. With the wrong conditions the sub-surface contamination could extend further than that (the scale of diffusion).

In summary the levels of oil contamination that can be expected in the water column and in the sediments following a spill depend on a) seastate, b) water depths and c) the dispersion into the water column. With an ARGO MERCHANT type spill, i.e. the slick moves offshore into deeper waters immediately after spilling, contamination of the water column is relatively shortlived. Sediment contamination is equally minor. However, with an AMOCO CADIZ type spill, i.e. slicks persist in the area and remain on the Grand Banks in shallower waters, there is increased chance of water column contamination. In areas of water column mixing, and under climatic conditions favoring such mixing, there is then a good likelihood of sediment oiling. While even under the worst conditions the water column is relatively quickly self-cleaned by dilution, sediment-bound petroleum hydrocarbons have a long residence time.

Short-term hydrocarbon concentrations that can be expected in water column during a spill are in the range 10 to 200 ppb, with an upper maximum of 300 ppb. These concentrations are for the upper ten meters, with a 10 to 25 ppb range for deeper waters. Under conditions of water column mixing, as in shallow waters or during storms, then the total water column can be expected to become contaminated uniformly. These concentrations will be short-lived, with return to lower (10 to 25 ppb) levels within a few days, and to background levels within a week or two weeks. There is a high degree of toxicity associated with newly spilled dispersed oil in the water column due to the presence in fresh oil of toxic lower molecular weight hydrocarbons. Normally these toxic components are lost from the surface slick by evaporation within 24 to 48 hours.

Hydrocarbon concentrations in bottom sediments after a spill are generally in the 10 to 100 ppm range. The extent of bottom contamination will depend largely on the size of the spill, depth of the water column and degree of water column mixing, and the duration of time the slicks remain in the area. There will be some bottom

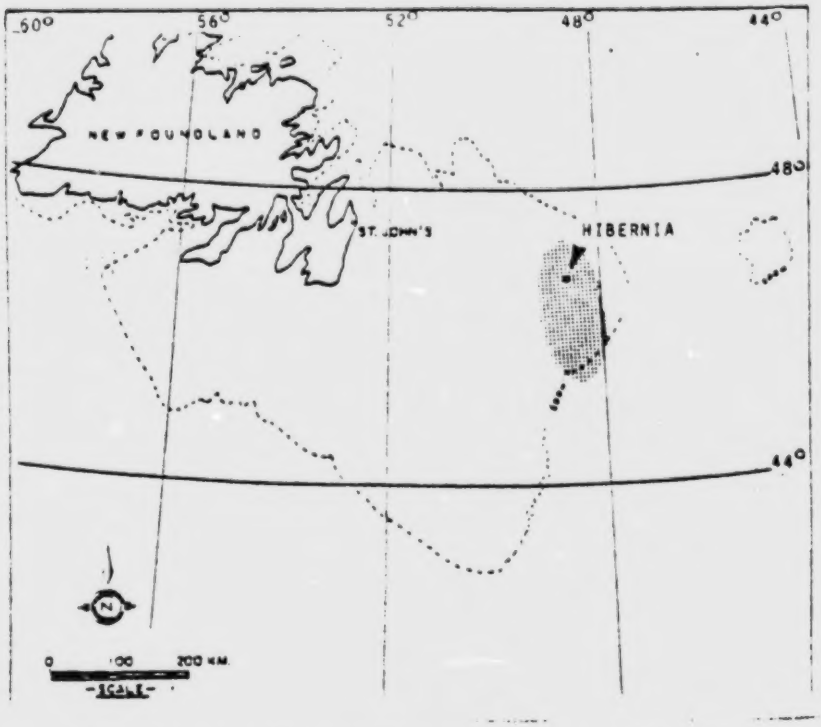


FIGURE 14. Projected oil-slick area for a 150,000 ton + crude oilspill from HIBERNIA, based on spread of AMOCO CADIZ spill (CNEXO et al, 1978)

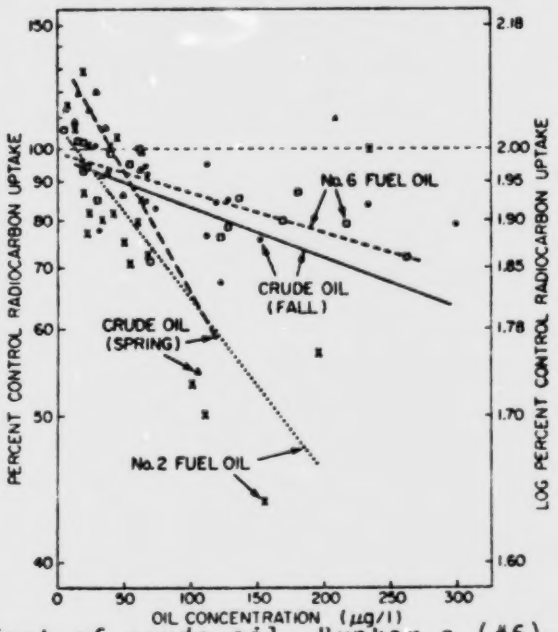


FIGURE 15. Effect of crude oil, Bunker c (#6) and #2 fuel oil on 14C-fixation by natural marine phytoplankton communities. (Gordon and Prouse, 1972).

contamination, even under the best conditions, but the extent of this contamination will probably be minimal. Sediment-bound hydrocarbons are highly persistent (five to fifteen years).

Potential Impact on Marine Biota/Sensitivity Levels

Impact of petroleum hydrocarbons on marine biota is directly dependent on the length of exposure, concentration, and on the chemical composition. As well, there are great differences between various marine organisms in their toxic sensitivity*. Not only are there species differences, but indeed the sensitivity varies with the different stages of the life cycle.

Biological studies during the ARGO MERCHANT spill covered the full range of the foodchain, with specific emphasis on marine fish. Although the sampling scheme was unfortunately inadequate for sound statistical assessment (this is the case with all real spill studies) the results did indicate negligible impact of the spill on the adult fish stock in the area. About five percent of the adult fish examined were found to have oiled stomach contents, and while there might have occurred some transfer of oil through the foodchain this possibility never was confirmed. By far the greater potential impact was on the egg and larval stages of marine fish, specifically cod and pollock (Table 10). Some abnormal development of fish larvae was noted, and a reduction in sandlance larvae was observed. Whether in fact the latter was due to oiling is not known. Also mortalities in cod and pollock eggs were noted in field collections made within the slick area. These effects appear to be oil-related as suggested by simultaneous laboratory experiments. Results of laboratory oil exposure studies of developing cod embryos with an ARGO MERCHANT like Bunker C oil indicated that concentrations of 250 ppb, as found near the wreck during the first days of the spill, were lethal to these cod embryos. Other work with eggs and larvae showed that their viability was reduced after exposure to Bunker C oil at lower concentrations. While verification of laboratory-based conclusions to hold true under spill conditions is extremely difficult, there is mounting evidence that the egg and younger stages of pelagic fish species may be at risk during a spill.

Impact on zooplankton and macrobenthos also was judged minimal following the ARGO MERCHANT. Oiling of zooplankton was observed, with a wide concentration range of oil in tissues from 0.24 to 117 ppm. Probably the higher values, up to 117 ppm, were due to oil droplets in the gut of the zooplankton, and not to intrinsic levels of hydrocarbons in the tissues. Ingestion of oil droplets has been observed at other spills (e.g. Conover 1970), and it is thought that copepod ingestion

* Vulnerability refers to the likelihood of oiling, while sensitivity refers to the likelihood of physiological deterioration or perturbation of some physiological process.

TABLE 9. Total hydrocarbon concentrations in surface sediment samples collected from RV *THALIA*, 12-14 June, 1978, as determined by UV fluorescence. ($\mu g\ g^{-1}$ wet weight crude oil equivalents).

Station* (Fig. 2)	Concentration	Sediment type
3	20.9	gravel
4	4.1	anaerobic silt
5	73.3	gravel, pebbles and large shell pieces
6	60.4	coarse gravel and shell
7	44.7	shell pieces
8	38.9	fine gravel, pebbles and shell
9	42.8	fine gravel
10	123	fine gravel with black lumps
11	7.5	gravel and pebbles
15	6.9	gravel and mud
16	14.4	gravel, pebbles and shell

*Grabbing for samples proved unsuccessful at all other stations.

TABLE 10. Summary of offshore biological studies, ARGO MERCHANT and AMOCO CADIZ.

ARGO MERCHANT[1]	
Fish	- adult - <5% with oiled stomach contents
	eggs - mortalities among cod & pollock eggs
	larvae - abnormalities in development
Zooplankton	- reduced biomass reported
	0.24 to 117 ppm oiling
Macrobenthos	- scarcely sampled, little trace of oiling
Birds	- mortalities
AMOCO CADIZ[2] [3]	
Fish	- no offshore work
Zooplankton	- reduced biomass reported, some mortality
	changes in digestive metabolism reported
Macrobenthos	- elimination of amphipod population[4]
	- massive mortalities in bivalves/heart urchins
Birds	- massive mortalities
	elevated mixed-function oxidase enzyme levels[5]

[1]In The Wake of the ARGO MERCHANT, 1978; [2] Hess, 1978; [3] Conan et al, 1978; [4]Cabioch et al, 1980; [5] Vandermeulen et al, 1978).

of dispersed oil droplets and the subsequent defecation may well be one of the main redistribution routes of oil from the surface slick into the bottom sediments. However, no physiological perturbations or massive mortalities were observed. The macrobenthos also appeared to have escaped impact of that spill, perhaps reflecting the nature of that particular spill - i.e. rapid movement offshore, little dispersion/diffusion into the water column, and ready loss of any contamination that did occur. In the end little oil reached the bottom sediments, and extent of bottom contamination was kept to a minimum.

The AMOCO CADIZ impact on the offshore marine biota of north Brittany is a study in contrast. Vast mortalities occurred among benthic organisms, including various species of bivalves and among heart-urchins. As well a complete population of offshore benthic amphipods was eliminated. Impact in the water column is less well documented. There were changes noted in certain digestive enzyme patterns in zooplankton, that coincided with the oiling of the Channel. As well, a higher than usual mortality of zooplankton was noted in collected samples by some workers, although the statistical figures for this latter observation are lacking.

However, impact on the fisheries in the form of fish mortalities was virtually non-existent. There was some oiling of fish tissues, as well as in those crustaceans that were economically important, but no measurable impact on the offshore fisheries was detected, either at the time of the spill or subsequently. One inshore groundfish population that was reportedly eliminated during the year subsequent to the spill appears now to have recovered or to be on the road to recovery, probably by recruitment from other nearby inshore stocks (Conan, personal communication).

The AMOCO CADIZ results again fit our understanding of oiling at sea. High turbulence and total water column mixing ensured hydrocarbon distribution throughout the water column, with rapid dispersion bringing the unevaporated lower molecular weight toxic components into rapid contact with benthic biota. Presumably it was this ready mixing and dispersion that accounted for the high mortalities in the benthic zone. Again, effects in the water column were minimal, reflecting the sort of hydrocarbon concentrations expected in the water column. The observed metabolic changes in the zooplankton populations certainly are expected at these concentrations, but requires further work and verification. This is a new assay and not well tested in marine oiling situations. However, similar observations have been obtained with other marine contaminants (notably heavy metals) and the technique would appear to hold promise as a future biological index of environmental pollution.

Less is known of the potential impact on phytoplankton, that is to say, from actual spill studies. There is a large amount of varied information available from laboratory studies, but unfortunately few deal with crude oil. It does appear that phytoplankton are as sensitive to oil as are zooplankton, and a range of effects has been

documented with various hydrocarbons and oils - depression of growth, depression of photosynthesis, reduction in ATP production, and a range of changes in cellular processes (e.g. Vandermeulen and Ahern, 1976; Johnson, 1977; Snow, 1980). Effects by crude oil have been measured in phytoplankton populations at low concentrations (100 ppb, Figure 15), but results become equivocal below 50 ppb where some enhancement of photosynthesis appears to occur. This should not be taken to mean that low level hydrocarbon contamination is good for phytoplankton. Rather, the process of sublethal contamination and impact is poorly understood and inadequately researched, so that for the moment few relevant or applicable studies are available.

In summary results of biological studies performed at two major spills (ARGO MERCHANT, AMOCO CADIZ) suggest no measurable impact on offshore adult fish stocks, at least not using the assays used to date. Egg and larval stages of fish are the more sensitive to oil exposure, with potential impact on their survival and viability during a spill (Table 10). Abnormal development of egg and larvae has been documented under spill conditions, and is supported by laboratory studies. The extent of these abnormalities within egg and larval populations is not known and only poorly understood. However, it is likely that at the expected hydrocarbon concentrations such abnormalities in development will occur to some degree.

It is expected that some temporal perturbations will occur in zooand phytoplankton. These will include oiling of the zooplankton by oil droplet ingestion, and the likelihood of mortalities. Phytoplankton populations will probably experience some physiological changes, particularly if the are concentrated in surface waters where hydrocarbon concentrations and toxicity during the initial spill hours will be highest. Effects on the plankton will be least in the event of a blowout with accompanying high rate of evaporation of a large portion of the lower molecular weight components (Grahl-Nielsen et al., 1977). Nonetheless, sensitivity levels of plankton, including larval crustacea that may be in the upper surface layers, are within the expected concentration of oil in water (Figure 16).

Impact on benthic biota is highly dependent on the conditions prevailing at the time of the spill. Under normal circumstances impact will be minimal. Some oiling of macrobenthos will occur, and it is likely that gut contents of crabs etc. will be oiled. However, oiling attributable mortalities will probably be small. The picture will probably change completely if the water-column is well mixed, especially during a storm with high sea-state. A much larger amount of oil can become incorporated into the water column under those circumstances, containing a proportionately higher amount of toxic components, with a greater contamination of the benthic sediments and biota.

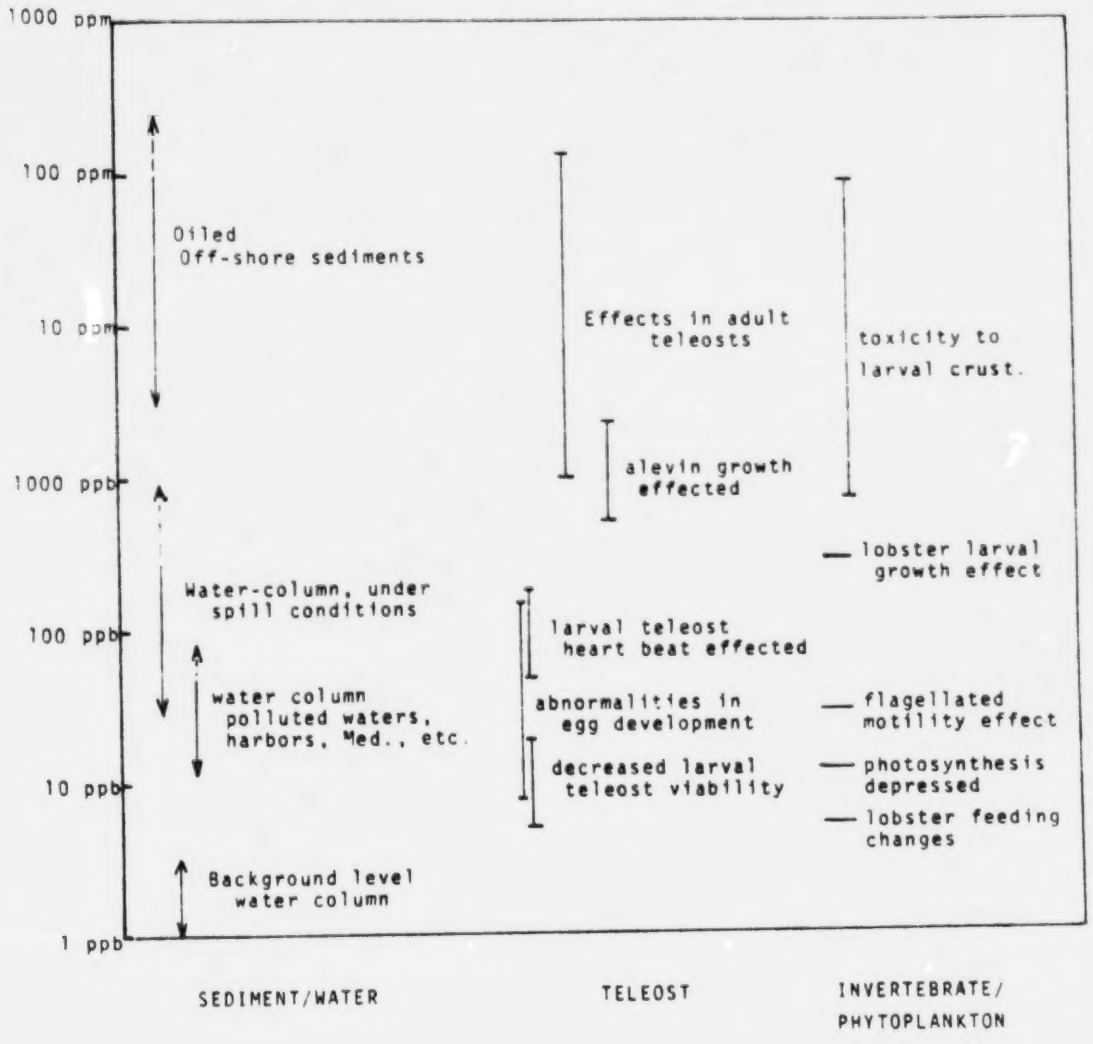


FIGURE 16. Ranges of petroleum hydrocarbon concentrations in offshore waters and sediments, and sensitivity levels in assorted marine biota.

TABLE 11

SOME OBSERVED EFFECTS OF OILS (CRUDE & BKR C) ON FISH

EGGS	Sensitivity	
	eggs < larvae < larvae with resorbed yolk sac	
	sensitivity varies with stage in life cycle	
	Abnormalities	
	delayed larval development	
	egg mortality - Argo Merchant	
	reduced larval viability - 10 ppm #6 fuel oil	
	abnormal development - abnormal backbone	
	abnormal dorsal fin	Argo Merchant
LARVAE	Sensitivity	
	plaice larvae < cod larvae < Atlantic herring larvae	
	pre-larvae (Black Sea flat fish)	(Bunker C)
	abnormal activity 10-100 ppb	
	mortality 1-100 ppm	
JUVENILES	Growth	
	growth decreased in 0.73-5.73 ppm Prudhoe Bay crude	
ADULTS	Physical	
	coughing rate changes 0.35-2.22 ppm Prudhoe Bay crude	
	avoidance from 1.6 to 497 ppm " (function of temperature)	
	larvae probably cannot avoid	
	schooling disorientation (Menidia) 167 ppm	
	Metabolic	
	O_2 consumption/heart beat/opercular movement 0.1-2 ppm	

(After Kuhnhold, 1978; Patten, 1977)

Discussion and Conclusion

Throughout the foregoing I have ignored the EKOFISK (Bravo) blowout and its impact on the biology of the area, despite the fact that the EKOFISK seems a tailor-made example of what might be expected on the Grand Banks. This was done purposely for the following reasons. Firstly - the potential spill hazard on Canada's east coast is not from blowouts, but from tanker traffic or pipeline break (viz. Dexter, this report). Secondly - the EKOFISK fortuitiously occurred at a time of little fish spawning activity and during a low abundance of adult fish (Lahn-Johannessen et al., 1977). Its impact then was necessarily minimal if not existent.

There are some aspects of that blowout that are of interest however. The blowout occurred in about 70 meters of water, and it is estimated that 30 to 40% of the oil was evaporated by the time it hit the water surface (Audunson, 1978). Oil did enter the water column, but contamination was found only in the surface waters. Interestingly no gradient in concentrations was found in the top ten meters, suggesting a uniform mixing in that upper surface layer. Only minimal oiling of the bottom sediments was found.

The spill also demonstrated the difficulties one encounters in mounting an instant spill study. Chemical identification of EKOFISK oil in water proved to be a major problem, since even non-polluted seawater contains a certain background suite of organic compounds that are extracted by the same methods used for petroleum hydrocarbons (Grahl-Nielsen, 1978). Absolute identification requires a combination of methods and sophisticated methodology (for ex. GC-MS), as well as the required sampling scheme to lend statistical soundness.

On the biological side, studies of potential impact on ichthyoplankton were hampered by both the scarcity of fish eggs and larvae and by the patchiness of their distribution. The same applied to observations on phytoplankton.

These problems were not reserved to the EKOFISK accident only. These same problems have dogged all study efforts on the impact of oil spills at sea. For the main the existing temporal or spatial variabilities have confused most efforts at documenting population changes or problems. Such changes can be documented with good confidence in oiled inshore marine environments (e.g. Journal Fisheries Research Board, 1978; Sanders et al., 1980). However, there we are dealing with higher hydrocarbon concentrations. In the offshore we are working at the lower limit of detection, using what are probably fairly gross indices of pollution (mortality, photosynthetic carbon-fixation) and in an environment that even under non-polluted conditions we only poorly understand.

That is not to say that pollution related impact on the offshore marine biota does not exist and does not occur. There is ample evidence from laboratory studies that links petroleum hydrocarbons to

problems with recruitment, fecundity, normal development of eggs and larvae, feeding, respiration, membrane permeability, enzyme activity, protein synthesis, ATP production, gametogenesis, tumor occurrence, carcinogenesis, and a host of other such problems. There is no doubt in my mind that these also can occur in the field, in the offshore marine environment, and that they indeed do occur. But how to measure them is another problem.

In summary, in the event of a major oilspill from the HIBERNIA field or over a similar area of the Canadian east coast, hydrocarbon concentrations can be expected in the water column that will be toxic to some parts of the marine foodchain, including fish eggs and larvae. This impact will consist largely of mortality, reduced viability and abnormal development of some of the larval stages. No massive impact on fish stocks by major oil spills has been demonstrated to date.

It is likely that zooplankton and phytoplankton will also experience toxic hydrocarbon concentrations, that may cause mortalties or physiological changes. The impact of this on offshore fisheries has not been demonstrated. Impact on benthic organisms will probably be minimal, except under certain circumstances as total mixing of the water column.

Water column contamination will probably disappear within days after the spill, with return to normal background conditions in a week or two weeks. Contamination of bottom sediments will persist for a much longer time, possibly for a decade or more.

Laboratory investigations suggest that, although oil impact in the field has been found to be minimal, in fact significant changes can and do occur but that in most cases we lack the ability to measure the changes.

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3. WHAT KIND OF OBSERVATIONAL PROGRAMS WOULD BE REQUIRED TO DETECT THE EFFECTS ON BIOTA?

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Two categories of biotic effects of accidental release of oil in the marine environment that one would want to observe can usefully be distinguished:- (a) mortality, (b) more subtle sub-lethal physiological or biochemical effects. Examples of the latter category that have been observed in the laboratory and/or in the field are paralysis, color changes (in lobster larvae), fish larval developmental deformities (e.g. larvae with abnormal flexures of the tail), reduced growth rate or fecundity of certain zooplankton species, tissue damage (e.g. to the primordial fin of fish larvae) and inhibition of feeding. Useful recent reviews on the effect of oil on zooplankton and fish are provided respectively by Wells (1980) and Penrose (1980). In addition to the above examples of sub-lethal effects, adherence of oil on feeding appendages in zooplankton forms and increased concentrations of non-naturally occuring aromatics or cycloalkanes in both plankton and nekton forms have been described subsequent to oil spills. These however are symptoms of the accident rather than biological effects. Laboratory studies however suggest that the latter symptom may result in the distrubance of the permeability of membranes. These effects, both lethal and sub-lethal, are discussed in detail by the previous speaker (Vandermeulen, this paper).

Different types of observational programs are required to detect the two categories of biological effects. Independent of the category, however, it is self-evident that the success of the monitoring programs subsequent to an event are critically dependent on the pre-event base-line studies. If one wishes to detect a mortality effect quantitatively, i.e. to determine what proportion of the population has been killed by an event, it is necessary to have an estimate of the population abundance prior to the event. In this section I will speculate on the precision of our present estimates of commercial fish population abundance at different phases of the life cycle (larval, juvenile and adult phases). Thus initially the question posed in topic 3 has been changed somewhat to "how large would the commercial fish mortality due to an accidental oil release have to be in order to be detected given the present monitoring programs?". Subsequently one can infer the monitoring programs that would be necessary to improve our population estimates, if this is indeed realistically feasible.

Fish egg and larval surveys have recently been initiated on the Scotian Shelf as part of the Scotian Shelf Ichthyoplankton Program (SSIP). There is not at present a program on a similar scale on the Grand Banks or further north. Thus in spite of the limitations of the SSIP fish larval population estimates, information on fish larval distributions for other eastern Canadian shelf waters is certainly less than that for the Scotian Shelf waters. It is of interest here to

consider how well the presently designed program provides estimates of egg and larval populations during a given survey (secondly the temporal frequency of surveys will be briefly considered).

The station densities for several larval surveys are shown in Table 1. The Scotian Shelf station density is at the low end of the range. Somewhat fortuitously the highest density is observed in the contiguous Bay of Fundy larval survey. From preliminary analysis there is the suggestion that the latter post-spawning herring larval survey population estimates are much better correlated with spawning stock biomass than is the case for the less dense George's Bank survey (Sinclair et al. 1979). Thus if one would expect a simple linear relationship between spawning stock size and larval abundance immediately subsequent to spawning, the correlation between the cohort analysis spawning stock estimates and the post-spawning larval population estimates should indicate the precision of the larval survey population estimates. Since the fecundity/fish weight ratio for herring is relatively constant (coefficient of variation of about 6%, Ware 1980) herring larval surveys are an appropriate species for which to evaluate the station density effect in this manner.

The effect of progressively lower station density on the relationship between spawning stock and larval abundance is shown in Figure 1. The R^2 value drops to 0.25 when only 10% of the stations are utilized (the stations were selected in a random stratified manner, the strata being indicated in Figure 2). The station density at this point approximates that observed during the present phase of SSIP.

It is tempting, but perhaps premature, to draw some general conclusion from the above data treatment. No doubt other fish larval distributions are not as patchy as that used in this example. Also assumptions are being made about the accuracy of the cohort analysis and the constancy of the fecundity/fish weight ratio. Nevertheless this is the only suitable data set available to investigate the effect of station density on the precision of larval abundance estimates. Tentatively then, I would suggest that the present station density of SSIP will not generate useful larval population estimates (this is not to be construed as a criticism of SSIP but rather of its ability to produce the specific data output in question). Species specific larval surveys at densities approaching 1 station per 100 square nautical miles are suggested if population indices are the desired output.

To adequately describe the year to year variability in larval abundance for a given species it is clear that several surveys of high station density within the period during which the larvae are available to the gear are required. The precise number, and their temporal frequency, is a function of several parameters including duration of spawning and the relationship between larval growth and mortality rates. Three or four surveys would appear to be the minimum requirement. Given four major commercial fish stocks in the immediate vicinity of the Sable Bank gas exploration area (4WX cod, 4WX haddock,

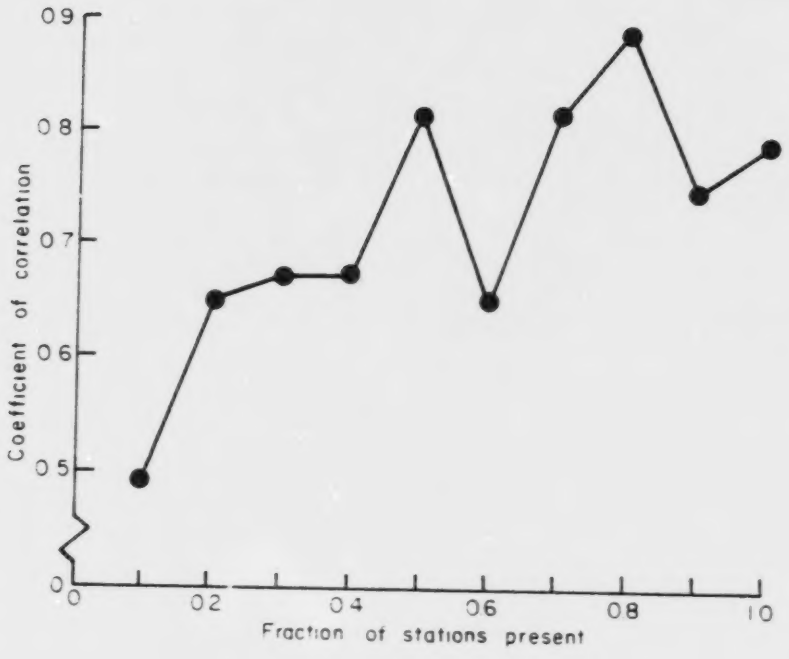

Figure 1. Effect of station density on correlation coefficient for the Bay of Fundy data set.

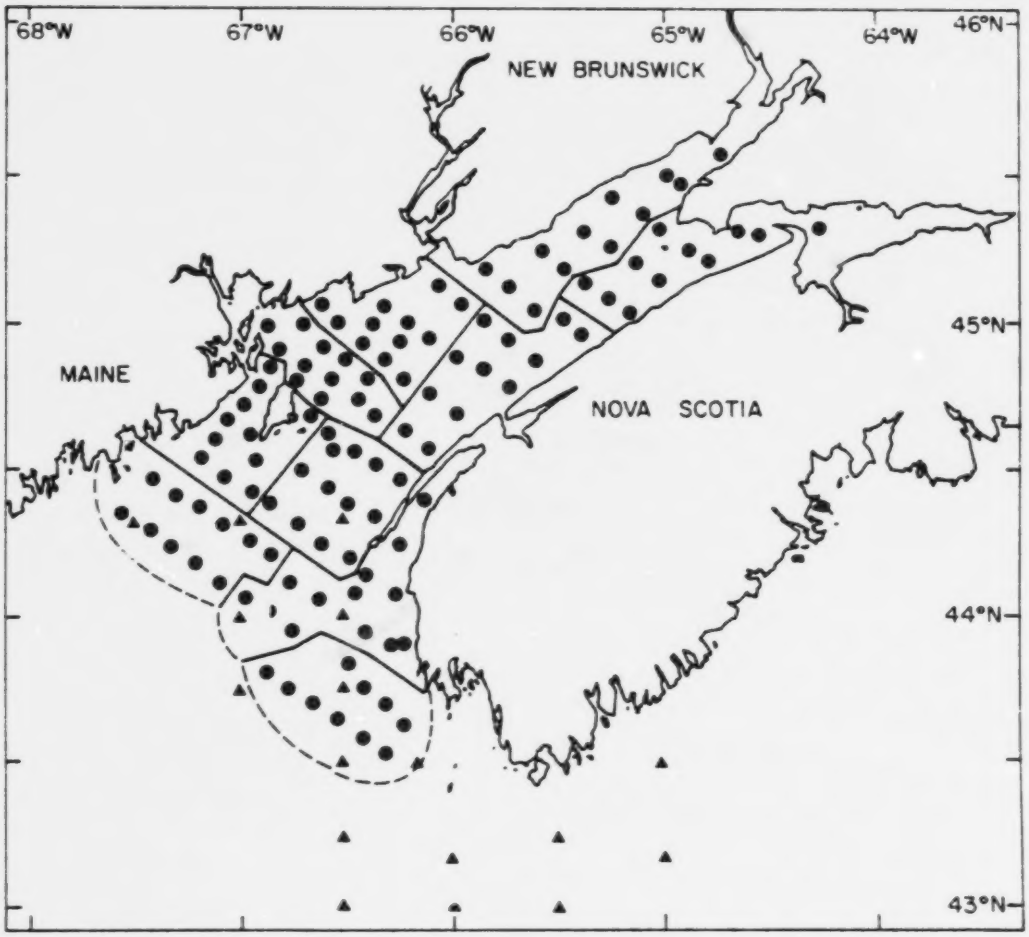

Figure 2. Areas selected for investigating variation in the Bay of Fundy larval herring data set.

Table 1. Comparison of survey coverage used in target species ichthyoplankton programs in North America and Europe.

Survey	Historical Mean Egg Potential ($N \times 10^{11}$)	# Stations Used	Area Covered Sq. n.m.	Station Density Sq. n.m. per Station
4T mackerel	300	60	24,000	400
4WX herring	779	116	5,912	51
5Ze herring	554	100	26,880	269
4VWX silver hake (S.S.I.P.)	?	150	6,000	400
North Sea cod	93	64	16,200	253
Pacific Anchovy (CALCOFI)	?	350	64,000	183

4VWX silver hake and 4VWX redfish) the ongoing pre-event monitoring necessary to provide useful larval population estimates very quickly becomes prodigious (4 cruises at a high station density per year for stock of interest). Extrapolation to Grand Banks stocks, if the above discussion of larval surveys is considered acceptable, is straight forward.

Juvenile abundance estimates for the major groundfish stocks are generated from various research vessel trawl surveys. A typical survey design, the stratified random Scotian Shelf RV survey, is shown in Figure 3. Generally only several stations within each stratum are sampled, and the standard survey is carried out once a year. Large year-to-year fluctuations in a given year-class abundance estimate (for example a year-class can be estimated by the survey at age 1, 2 and 3 prior to being recruited to the fishery) are common due to "availability" changes (Table 2). Thus single estimates of juvenile abundance using RV surveys have very large confidence limits. It seems safe to conclude that it would not be possible to statistically detect anything smaller than order of magnitude mortality effects at the juvenile stage using our present monitoring program. For greater precision in juvenile abundance, stock specific surveys would need to be considered.

Once a year-class enters the fishery however, the estimates of abundance at age become progressively improved. In the assessment procedure, for well sampled stocks, both research vessel and fishery-dependent data are used in combination to produce year-by-year estimates of numbers at age in the population. Adult biomass confidence limits for the best case stock would probably be narrow enough to detect a 25% mortality.

In sum the pre-event and post-event monitoring programs required to detect the lethal effects of an oil spill (i.e. to estimate what proportion of the population has been killed) greatly exceed our ongoing monitoring programs established for assessment purposes. It is my somewhat subjective conclusion that present monitoring cannot detect changes in larval mortality rates, and at best could only detect massive kills at the juvenile stage. The adult population sizes however, in certain cases, can be measured with considerable precision, such that much smaller oil induced mortality rates could be detected.

Monitoring for sub-lethal effects would appear to be much more cost effective. Specific pre-event monitoring of the selected sub-lethal effects is still required. However the aim in this case is to take a representative sample of the population in question rather than to sample the whole population. Thus field sampling requirements for sub-lethal effects are much less demanding. The "normal" distribution of the "chosen sub-lethal indicators" (e.g. % deformities in fish larval tail flexures) needs to be described prior to the event. Depending on the indicator however this could involve very time consuming laboratory analyses. Subsequent to the event representative sampling of the appropriate life history phase for the given

Table 2. 4VsW cod research vessel survey population estimates with the two anomalous sets in 1973 included. Circled numbers indicate examples of "availability" changes

AGE	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
0	97	23	0	0	866	69	0	0	174	1017
1	1273	1539	6210	16128	5174	3372	2242	808	3053	1213
2	16123	7680	9674	122780	32961	8412	14066	10145	13065	10612
3	5196	35664	11881	104965	19245	13000	16098	26372	31245	16044
4	7682	8027	31536	59948	5623	6171	10187	17059	34205	16595
5	3734	15803	5812	22524	2017	2959	6621	11353	9461	18075
6	1227	5775	5989	1870	2244	675	1264	4893	3490	9053
7	1532	3459	1621	2907	372	867	656	1081	889	2696
8	466	1475	547	901	463	235	1308	878	185	1009
9	104	638	495	431	224	433	0	244	90	411
10	701	471	153	910	340	91	1180	223	158	152
UK	274	112	0	202	44	74	36	114	53	253

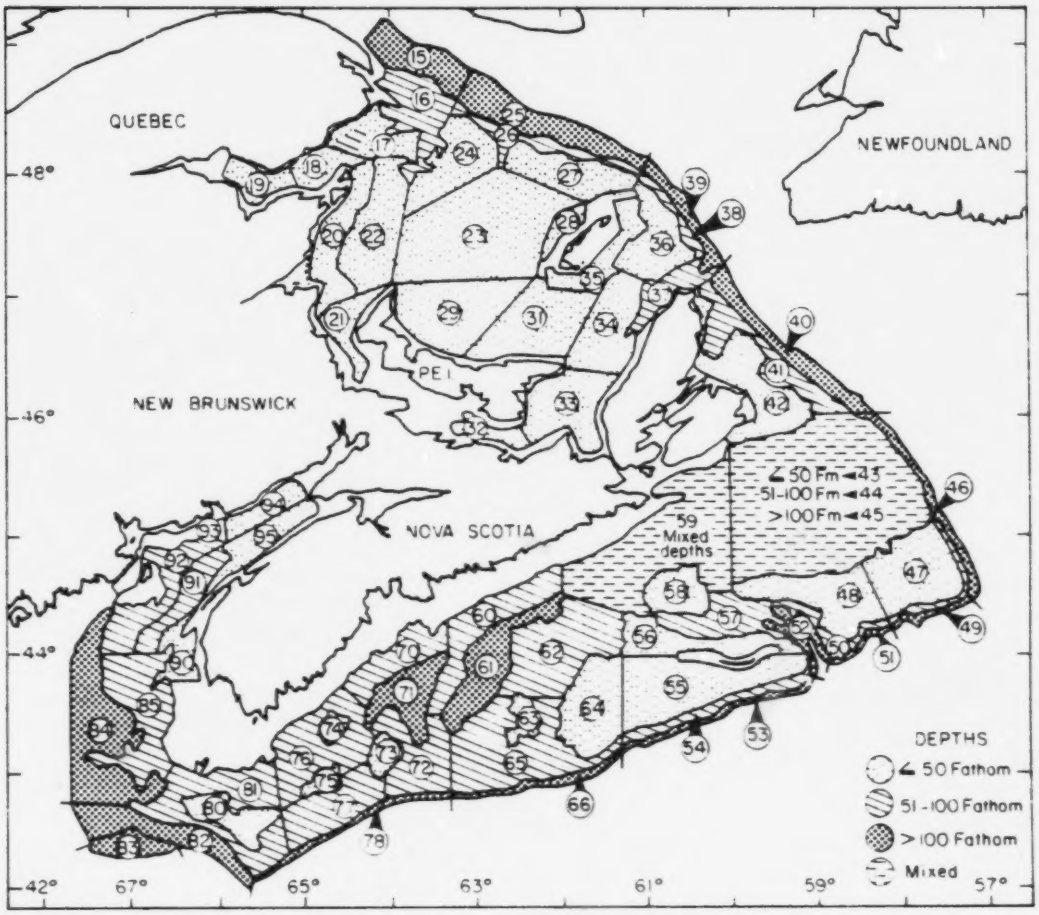

Figure 3. Stratification scheme for ICNAF Division 4T, V, W, and X.

indicator would be required. This could be done, perhaps preferably away from the spill area when the population is in an aggregated form, such as during spawning or overwintering.

It would be presumptious of me to suggest or discuss the best sub-lethal indicators but the following is an outline of a post-event "sub-lethal effect" monitoring program, intensive sampling in relation to point source for:

(a) water chemistry for dissolved fraction;

(b) external microscopic examination - e.g. oil on feeding appendages or in gut of zooplankters;

(c) histological examinations of respiratory surfaces and tissues(?);

(d) analyses of tissues for specific aromatics;

(e) representative population sampling of chosen oil pollution indices (?); and

(f) plankton distributions.

From the above, and the baseline studies, at best one could only infer the geographic area within which certain sub-lethal biotic effects were observed. The importance of these sub-lethal effects on population biology or on community interactions cannot however be inferred given the present state of the art. Thus, although cost effective, the quantitative impact of an oil pollution event on the fisheries in the area would not be predictable from a "sub-lethal" monitoring program.

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4. WHAT IS THE LIKELIHOOD THAT SUCH EFFECTS WOULD IMPAIR RECRUITMENT, AND THAT SUCH IMPAIRED RECRUITMENT WOULD BE SEPARABLE FROM NATURAL VARIATION?

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INTRODUCTION

The potential offshore development of oil and gas in Atlantic Canada has raised legitimate concerns about the possible effects of these operations on fisheries. In response to a similar problem, Johnston (1977) estimated the impact of oil spills of various magnitudes on the annual fish production of the North Sea. To simplify the situation, he assumed that the North Sea was a homogeneous production system with no unique temporal or spatial properties. Johnston (1977) concluded that the impact of petroleum development on the open-water fisheries would be negligible compared to the total value of the resource. Although Johnston's approach is instructive, in practice the fishing industry is organized to exploit specific stocks, or stock complexes. This may be an important distinction to remember when appraising possible effects.

There seems to be general agreement that hydrocarbons are most toxic to the early life history stages of fish. Indeed, many fisheries biologists believe that much of the observed variation in the numbers of young fish entering the fishery each year - biologists refer to this event as recruitment - is due to natural environmental factors which affect larval growth and mortality rates. Another significant source of variation is the reproductive effort of the parent stock.

For these reasons, the spawning times of different species and the scale of distribution of their eggs and larvae in relation to oil spills of various magnitudes should be examined. We will also consider two questions:

(a) can the effect of a single spill be separated from natural recruitment variability, and

(b) what are some of the long-term effects of petroleum development on fisheries?

As an example, I have chosen the fisheries of the Nova Scotia Continental Shelf.

Spawning Times and Scales of Patchiness

Under the current exploitation regime, seven species account for 80% of the total landings from the Scotian Shelf. Six of these species spawn offshore; of these, five produce pelagic eggs and larvae, whereas redfish live bear their young. Figure 1 shows the spawning times for the major species which liberate pelagic eggs (Leim and Scott, 1966).

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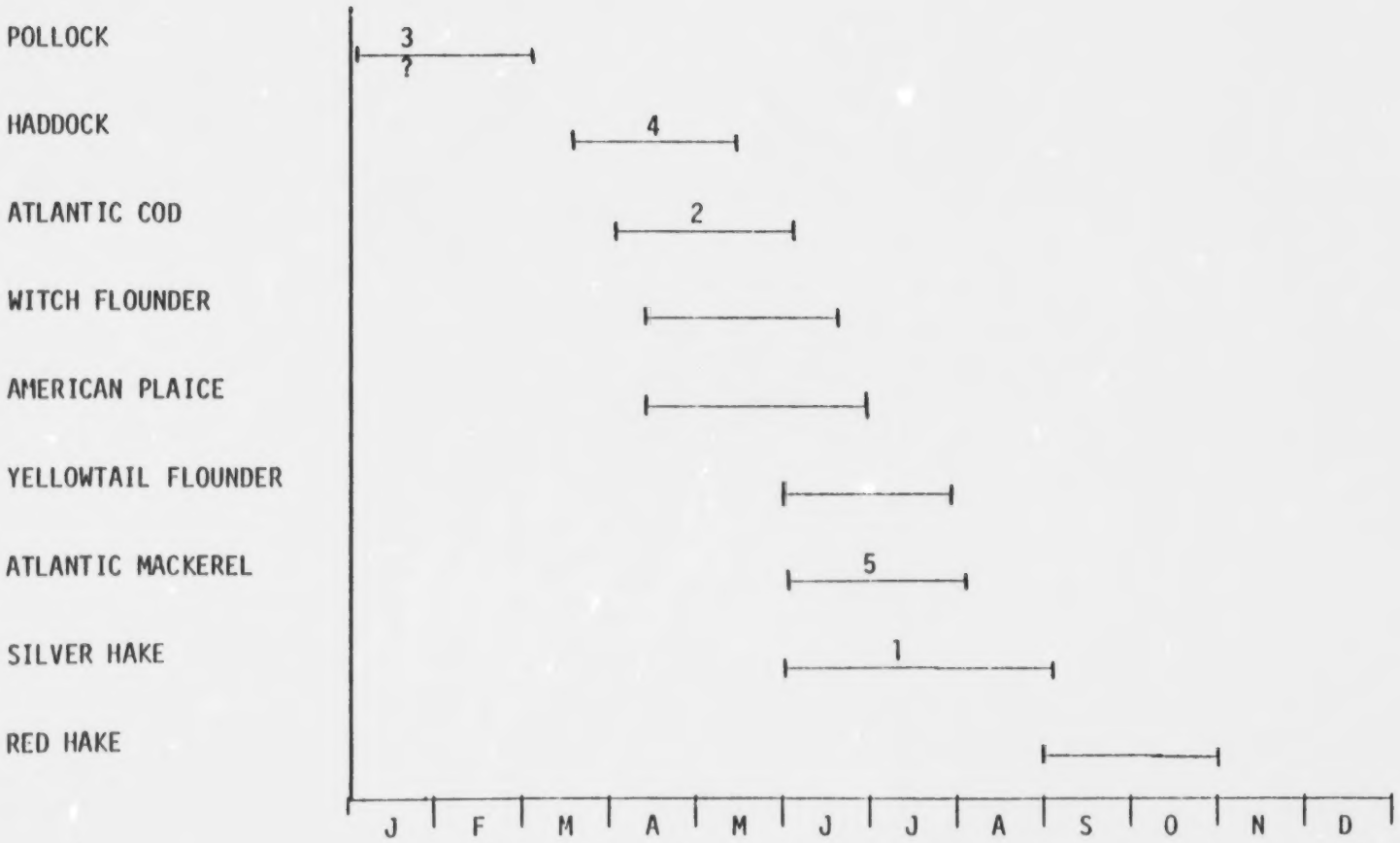


FIG.1 Spawning times of major commerical fish species on Nova Scotia Continental Shelf. Numbers indicate current importance in total landings.

Notice that each species spawns at a discrete time, in a well defined progression which spans the entire year. Some species, therefore, is always at risk. So far as the important commercial stocks are concerned the worst time for an oil spill would be June to August, inclusive, followed by the January to May period.

Unfortunately, we know very little about the scales of patchiness of the early life history stages of these stocks, except for silver hake. The Scotian Shelf ichthyoplankton survey program indicates that the main spawning area of this species is of the order of 18,000 km^2 (Figure 2, from A.C. Kohler, unpublished report).

An oversimplified assessment of the relative impact of a spill of different magnitudes on this stock is outlined in Table 1. According to the MIT report cited by Johnston (1977), the maximum stable slick area resulting from a 400,000 metric ton spill is about 2,400 km^2. Thus, at worst, a major catastrophe at the right time and place could cover about 14% of the silver hake spawning area. Table 1 shows that spills of lower magnitudes will naturally have a smaller impact.

It is important to note, however, that the potential mortality will be considerably less than the figures in Table 1 imply. First, only a fraction of the maximum slick area will contain a sufficient concentration of contaminants to be toxic to hake eggs and larvae. Second, there is a high probability that during the 42 days required for a 400,000 ton spill to reach its maximum area, a significant fraction of the oil would have been advected off the Shelf (the exact probability, of course, depends on where the accident occurred). Third, assuming oil is mixed throughout the top 20 m of the water column (Johnston, 1977), the effect on silver hake would be small since their larvae tend to be concentrated at the bottom of the mixed layer (ca. 40 to 60 m; B. O'Boyle, personal communication).

Natural Recruitment Variability

Our current ability to detect the effect of an oil spill on recruitment depends on the natural variability of this process due to environmental and fishery related causes. Two extreme examples of recruitment variability are illustrated in Figures 3 and 4. Comparison of these data indicate that the southern Gulf of St. Lawrence cod stock has exhibited much less variation than 4VWX silver hake in recent years. Indeed, in the event of a significant accident, the affected year-class of cod would have to be 3 1/2 times smaller than the mean recruitment before one could argue with any statistical confidence that the observed size of the year-class reflects a significant oil-related mortality. By contrast, the recruiting year-class of silver hake would have to be about 12 times smaller than the mean to detect an effect.

If the impact of petroleum hydrocarbons on the early life history stages is as small as we think it is, then it seems unlikely that the effects of single spill - even of major proportions - could be

TABLE 1 SCALES OF PATCHINESS

Oil Spill Magnitude (t)*	Annual Frequency*	Stable Maximum Slick Area (Km^2) * S_A	S_A as % of main area of conc. of silver hake larvae **
400,000	0.02	2400	13.6
100,000	0.04	860	4.9
10,000	0.2	160	0.9
1,000	1	28	0.2
50	10	2.9	0.02
2.5	100	0.4	0.002

* From Johnston (1977)

** During the period of peak spawning in August, 1976, silver hake larvae were concentrated in an area of 17674 Km^2 to the south-west of Sable Island.

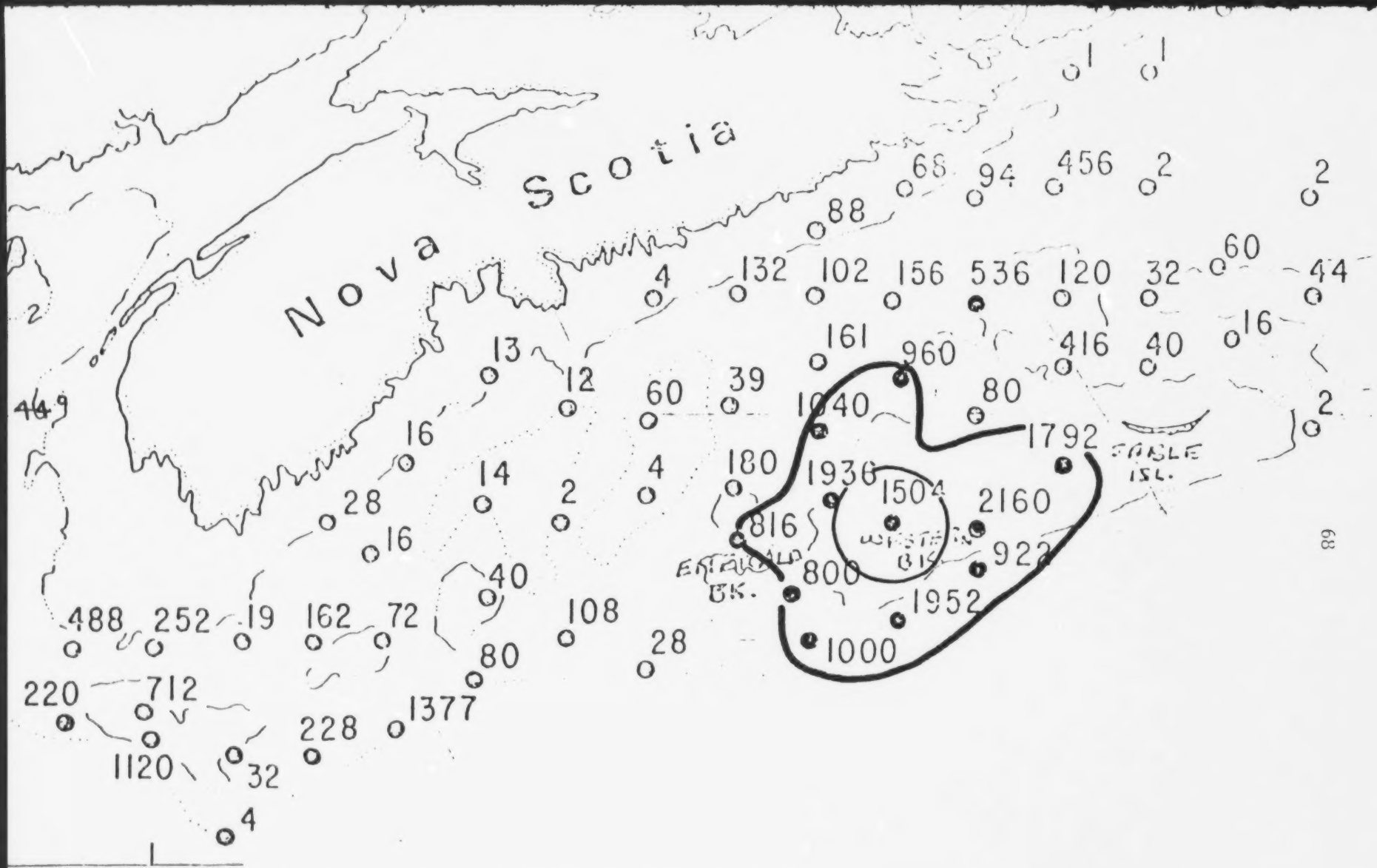
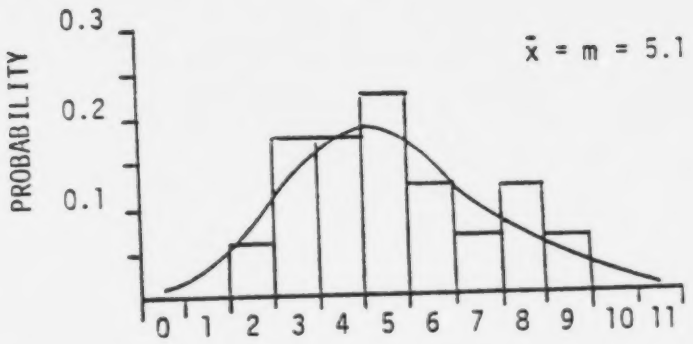


FIG. 2 Distribution of silver hake larvae in August, 1976 (Kohler, unpublished data). The area of highest abundance is outlined and represents about 17,700 km^2. For comparison the small circle represents the maximum stable slick area (2400 km^2) for a 400,000 metric ton oil spill.



Arithmetic Mean	= 6.20×10^7 Fish
Std. Deviation	= 1.95×10^7 Fish
$S/\bar{x}$	= 0.31
Log_{10} Mean	= 7.783
Log_{10} Std. Deviation	= 0.143
$S/\bar{x}$	= 0.02

Fig. 3 Recruitment variability of ICNAF area 4T Atlantic cod at age 3, 1961 to 1977. The raw recruitment numbers (Lett, 1978) were standardized ($[N(3)/1 \times 10^7]-1$) and arranged into relative size classes. A variance to mean test indicates that the transformed distribution shown above fits a poisson series. The arithmetic and logarithmic means and standard deviations of the raw data are also shown.

distinguished from natural variability. This generalization is most likely to hold for species like haddock, herring, and silver hake, which typically exhibit the highest recruitment variation (Garrod and Colebrook, 1978).

Long-term Effects

In contrast to a discrete event like a spill, which is relatively short-lived, oil related developments can cause a progressive increase in the background level of hydrocarbons. Long-term effects of residual oil on fisheries could conceivably involve a number of factors.

Hydrocarbon fractions typified by pentane inhibit primary production. Fortunately, this effect only lasts a few hours or days because of the volatility of these fractions (Johnston, 1977). Octane-like fractions, however, are more inhibitory, less volatile and less soluble. Johnston (1977) noted that the period of inhibition in this case may be as long as weeks or months.

As a rule, the relationship between primary production and fish yield is linear (Akenhead et al., 1979). At maximum sustained exploitation the observed relationship can be described approximately by:

$$\text{Fish yield } (gCm^{-2}yr^{-1}) = 0.0021 \quad \text{Primary Production } (gCm^{-2}yr^{-1})$$

A long-term decline in primary production, therefore, ought to have a proportional effect on the total fish yield. The actual reduction however may be proportionally greater for some species than others depending on the extent to which the primary production cycle is altered, and how this is translated into food resources for fish further down the food web.

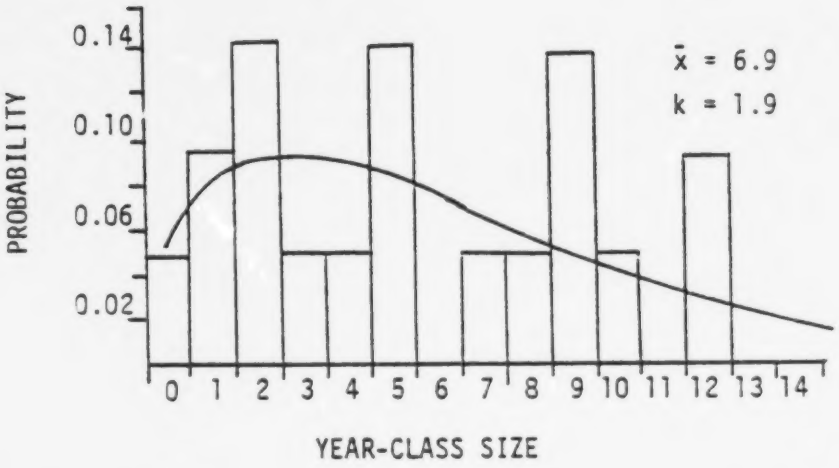
Other long-term effects of an increase in the background level of petroleum hydrocarbons on fisheries might include:

(a) Reduction in growth rates with an attendant fall in reproductive output of the mature stock, since fecundity depends on body size.

(b) Reduction in fertility due to accumulation of hydrocarbons in mature fish.

(c) Increase in the natural mortality rates for all ages due to metabolic disorders, increase in incidence of carcinomas and sarcomas (Stich et al., 1976).

Johnston (1977) remarked that it is impossible to assess these factors because "there are no field observations to illustrate the



Arithmetic Mean	= 7.93×10^8 fish
Standard Deviation	= 5.65×10^8 fish
$S/\bar{x}$	= 0.71
Log_{10} Mean	= 8.788
Log_{10} Std. Deviation	= 0.335
$S/\bar{x}$	= 0.04

Fig. 4 Recruitment variability of ICNAF area 4VWX silver hake at age 2, 1959-1979. The raw recruitment numbers (Clay and Beanlands, 1980) were standardized ($[N(2)/1 \times 10^8]-1$) and arranged into relative size classes. The transformed data shown above were fit to a negative binomial distribution. The arithmetic and logarithmic means and standard deviations of the raw data are also shown.

long-term effects of weathered crude on open sea organisms". In principle, however, the possible impact of hydrocarbons on stock recruitment and production could be estimated statistically by a cost-effective monitoring program. In this context, perhaps, it would be prudent to measure population parameters which are not routinely assessed by fisheries management biologists. A list of such parameters might include: size-specific gonad weights (fecundity), whole body or tissue hydrocarbon levels, incidence of carcinomas and sarcomas in different age groups of selected species.

Conclusion

In general, Johnston's (1977) appreciation of the situation in the North Sea is probably equally valid here:

> "....on average, or even at worst, the impact of offshore oil pollution on fisheries will be negligible or small, much less than factors such as over-exploitation or unsuccessful stock recruitment".

However, we should keep in mind that Johnston assumed a homogeneous ocean where plankton and fish production occurred uniformly everywhere throughout the year. This superficial abstraction of the problem ignores the fact that spawning is often a localized phenomenon, and that primary and secondary production are highly seasonal processes. Despite these complications, natural recruitment variability tends to be so high that it is unlikely that we could detect the effect of a spill of major proportions, even if it occurred at the most sensitive time and place.

The long-term effect of an increase in the background level of residual hydrocarbons on fisheries might be just as difficult to assess. This problem could be examined statistically, however, by establishing a monitoring program.

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5. WHAT CONSEQUENCES FOR OFFSHORE FISHING OPERATIONS MAY BE EXPECTED?

Given the likely probabilities for release and behaviour of spilled oil, what consequences for offshore fishing operations can be expected?

D.J. Scarratt (DFO/FM at St. Andrews)

Stock Population Dynamics

From the foregoing papers it seems highly unlikely that the accidental release of oil in offshore waters will have any significant effect upon fish populations. By significant, I mean any effect which causes a detectable change in population structure or the success of a year-class that is unequivocally attributable to that spill. That is not to say that the actual mortality of fish eggs or larvae may not be increased over some part of their distribution range, but rather that our capacity to measure the impact of that increase on the population as a whole is so small that the impact would, effectively, be undetectable.

The important point to note is that increased mortality will likely occur over part of a year-class of eggs or larvae, and that only perhaps in extremely localized conditions might the effects be serious. These conditions are likely to be found only in restricted coastal waters where dispersion of oil is limited by the land, and where discrete, localized stocks or populations might exist. An example of this is the effect of AMOCO CADIZ crude oil on the 1978 year-class of sole in the Baie de Morlaix. The nearest offshore parallel I can conceive might perhaps be shallow spawning herring stocks on Georges Bank, if by chance oil developments took place near there, and a massive spill was coincident with heavy weather at the time of spawning or during the early larval phases.

There has been a suggestion that a medium fuel spill off Stockholm might have caused reduced spawning success in herring several months later, but the evidence is equivocal. Once again though, it seems likely that such effects would be exacerbated in confined waters, and their likelihood reduced offshore.

It seems a reasonable assumption then, that no major changes in commercial fish stock populations offshore are likely to be attributable to oil spills, and that this factor is unlikely to be important in fish stock assessment exercises, nor in the determination of catch quotas. It is a reasonable corollary that other accidental and routine discharges from rigs and platforms will have similar nonsignificant effects.

Dead Fish

Similar arguments apply to the likelihood of finding dead fish in the vicinity of, or downstream from, an oil spill source (this discounts increased mortality among exposed fish eggs and larvae). The exceptions are likely to be in confined waters and hence insignificant except at the local level. The only factor might be high density brine or formation-water of low oxygen concentration which, when discharged, might pool in seabed depressions unless adequately dispersed. However, these effects too would be local and easily countered.

Tainting (Imparting of Oily Off-flavours in Commercial Species or Products)

This is perhaps one of the more insidious and least easily resolved questions, due in part to the subjective nature of taste perception. It is linked closely with the question of 'contamination' but the distinctions are perhaps worthwhile exploring.

There are at present no legal standards for the presence of hydrocarbons on or in fish. During the KURDISTAN incident, and in other incidents before and since, fisheries inspection officers (and commercial buyers) have rejected catches or samples that have had visible traces of oil. In one case at least, such a sample showed no sign of contamination when analyzed spectrofluorimetrically.

By contrast, lobsters analyzed by taste panels detected instances of 'slight oily off-flavours' in wild lobsters captured in areas heavily oiled by KURDISTAN Bunker C. These lobsters were subsequently shown to have 3-15 times as much fluorescent hydrocarbons in their tissues. Nevertheless, apart from confiscating catches visibly contaminated with oil, the Fisheries Service did not interfere in any of the Cape Breton fisheries, except to post advisory notices on clam flats where severe oiling had taken place. There is thus a measure of unevenness in how closures or confiscations have been imposed.

It is clear that in spite of their capacity to metabolize certain hydrocarbons at least, finfish are not immune from tainting. At least two cases are before the courts now. There seems little doubt that in one case tainting did actually occur as a result of contact with either Bunker C or light fuel, and the courts will decide whether a culprit can be identified. There was also contamination of mackerel on a number of occasions during the KURDISTAN episode. In all of these occasions so far listed, the fish were already confined in nets at the time the contamination (and subsequent tainting) took place. It seems unlikely that fish, at large in the open ocean, will pick up sufficient oil to become tainted, although the likelihood that this might happen in confined, coastal areas should not be ruled out.

It is quite likely that in the event of an oil spill fish caught in oiled nets, or retained in nets (e.g. a seine) which subsequently

become oiled, would very likely be contaminated, and thus subject to market rejection or downgrading to fertilizer. This might require the need for increased vigilance by quality control inspectors. There could well be a relationship between tainting, contamination and the nature of the oil. Light fractions might be more likely to induce tainting, while heavier crudes, being less easily dispersed, might be more likely to cause contamination.

Fouled Gear

This section deals with two meanings of the word fouling: the physical contamination of fishing gear by oil; and the snagging or catching of gear on obstructions. The first has already been alluded to.

(a) Virtually every oil spill of more than a few gallons volume has resulted in fishing gear becoming partially or wholly coated with oil. For lighter oils this does not pose a particular problem in that water turbulence and general handling cause it to wash or wear off rapidly, for heavier crudes or residual oils this does not happen and nets, ropes, buoys, not to mention boats and their crews, become liberally coated. The effect on catches has already been discussed. To some extent fishermen can see oil slicks and thus avoid shooting gear in areas where the likelihood of oiling is high; however, a fixed gear (longlines, traps, gillnets) are perhaps less flexible and if oil is dispersed subsurface (as was KURDISTAN oil), all fishing methods are equally vulnerable.

Discussions with American fishermen in the Gulf of Mexico revealed that the presence of large slick areas over or near established fishing grounds following the IXTOX 1 blowout had the effect of displacing vessels off those grounds and into adjacent areas where slicks were less common or absent. Fishermen who habitually fished those grounds were themselves disrupted and, in some cases, displaced by this increased fishing activity. There were other sequelae which are discussed below. A major part of the slick tracking and forecasting effort went into pinpointing areas where fishermen would, or would in future, encounter oil and hence run the risk of contaminated catches.

(b) Apart from the biological implications of oil, the single item most discussed by fishermen seems to be the question of submarine debris or junk and active or abandoned structures on which nets and other gear may become torn or hung up. This was a major bone of contention following oil development in the Norwegian sector of the North Sea, and in other sectors as well. In spite of protestation that oil and shrimp fishing co-exist amicably in the Gulf of Mexico, fishermen maintain

there is much abandoned or jettisoned equipment in the Gulf, and each fisherman has his 'hang' book: private notations of sea-bottom irregularities where snagging of gear is likely. One of the perceived problems of the IXTOX spill was that in avoiding heavily slick-contaminated areas, fishermen were forced onto grounds they were less knowledgeable about, and there was a concomitant increase in torn gear. By contrast with the eastern seaboard, the Gulf of Mexico has many thousand abandoned wells, the legacy of 30 years of drilling and development; it is, however, worthwhile recognizing the problem and its variants in order to prepare ourselves.

There is one thing that might be done in anticipation. Only in rare instances are fish distributed at random over the sea bed. If the exact locations of fishing activity were accurately charted, it might well be that sufficient flexibility exists to site oil production structures in areas away from prime fishing sites. It may be that distances of a kilometer or so might be significant to fishermen, and yet be within engineering limits.

Amendments to Fishing Strategy

It seems unlikely (conclusion of section 1) that oil spills or other discharges will cause detectable changes in fish stock population dynamics or in management strategy for them.

It could be that the need to avoid gear fouling and risk of subsequent catch contamination, or the unlikely event of tainting of wild stocks (perhaps George's Bank scallops might be vulnerable) would encourage official closure of limited areas, or cause fishermen to avoid those areas while the risk was present. Depending on the time of year or season, this might have the effect of putting additional pressure on adjacent stocks, or of losing part of a quota or TAC, particularly if the oil slick area was large and the discharge of long duration. The KURDISTAN lost about 7,000 tons of oil when it broke up, and the effects were felt as far as 200 miles east and west at times up to 4 months after the accident.

I cannot see any specific likelihood of differential treatment of foreign and Canadian fishermen in respect to oil discharges, unless, for some hitherto unpredictable reason, some stock does become contaminated in some way and we elect to allow others to fish it up for its reduced value, rather than do it ourselves.

6. WHAT WILL BE THE EFFECTS IF ANY, OF COUNTERMEASURES?

R.H. Cook (DFO/FM at St. Andrews)

To date the application of countermeasures for oil spills in the marine environment has been directed towards the mitigation of oil spill effects in the coastal zone. In this paper, consideration is given to pollution impacts related to offshore developments and a comparison of oil spills from shipping and offshore developments is made. Currently available counterspill technology and its potential for application to the offshore area is discussed.

The Problem

With the potential of oil and offshore developments on the Canadian east coast, it is critical and timely that consideration be given to the question of the use of countermeasures during an offshore spill. Notwithstanding the relatively low probability for a major event (blowout, tanker collision, etc.), a condition of chronic loading of the marine environment is produced by the numerous operational activities in the production and movement of oil from the platform and storage units to shore. Spill prevention measures related to routine operations are regulated and controlled by local management.

To respond to a major oil spill resulting from an offshore development requires considerable planning. Before this planning can proceed, the question of governmental responsibilities must first be addressed. If shipping is involved, then the Canadian Coast Guard (under the Shipping Act) is mandated to act. If the spill arises from an offshore oil platform, then the Department of Energy, Mines and Resources is responsible for ensuring appropriate countermeasures are in place. Oil spills from offshore developments north of 60°N fall within the jurisdication of the Department of Indian and Northern Affairs. As a part of the approval process for offshore exploration and production, industry is required to prepare contingency plans detailing what actions they would institute, given an oil spill emergency. These plans are given comprehensive review within federal departments and by the province(s) concerned. The application of effective countermeasures during a major offshore oil spill is dependent on three factors:

a. Appointment of an experienced On-scene Commander (OSC) with broad authority and resources to deal with the emergency;

b. The preparedness of responsible governmental agencies and industry in having available:

   - update contingency plan,
   - logistic and observational support,
   - trained personnel for application of countermeasures, and

- updated environmental data base (marine resources, oceanographic, meteorological, etc.) for area.

c. The natural environmental countermeasure effectiveness will depend in large measure on factors beyond human control, e.g. sea state, wind level, presence of ice, visibility (fog), etc.

In considering counter measures applicable to a major oil spill in the offshore environment, a number of comparisons and contrasts with oil spills from ships and offshore developments come to mind:

Spills from Shipping:

- cargo contents are difficult to determine accurately and can include wide range of petroleum products from Bunker C to light fuel oils;

- chemical characteristics of cargo is highly variable with respect to trace and other contaminants;

- site of spill is highly variable on a geographic basis (viz. grounding or collision); and

- countermeasure experience is considerable, especially with respect to mitigation of nearshore effects.

Spills from Offshore Operations:

- the product composition and chemical characteristics are essentially known beforehand;

- the sites of major spills (viz. well and platform locations) can be determined beforehand and specific countermeasures for these sites can be developed; and

- the quantity of oil lost is indeterminate, the quantity released being contingent on the effectiveness of engineering countermeasures applied at the wellhead (in the case of a blowout).

It might be concluded that in planning countermeasures for offshore developments this availability of specific siting and product composition are advantageous. This background enables the development of specific countermeasures such as the compilation of marine resource sensitivities in the area and an oceanographic data base, the development of oil spill trajectory models for the site, and methods of interfacing with the fishing industry operating in the vicinity of a major spill.

Other Aspects of Offshore Developments

This paper is primarily focused on the countermeasures associated with a major spill from an offshore oil development or production facility; however, the effect of operational releases of oil and other contaminants arising from the offshore industry, and physical disruptions to aquatic habitats should not be overlooked. Although these "other" pollution sources are controlled under governmental regulation, the continuous nature of such discharges to the marine environment in the vicinity of offshore facilities does require attention. These sources would include:

(a) drilling muds - their composition and content of hydrocarbons and other contaminants (trace metals, biocides, etc.);

(b) oil discharged from transportation associated with offshore facilities (SPM systems, pipeline connections from floating holding tanks, bilge water discharges and/or bilge water treatment facilities, etc.); and

(c) other wastes from platforms or oil transfer ships.

In addition to the chronic release of oil and other pollutants, offshore developments may also be responsible for other effects which impinge on fish habitat. Their effects would include physical disruptions to habitat associated with port developments, pipeline construction, and solid waste disposal at sea and at land-based sites.

When reviewing the environmental implications of the offshore oil industry to the marine environment, it is clearly not adequate to consider only the countermeasures required for a major oil spill emergency; the effect of the associated chronic pollution sources must be assessed with appropriate control and mitigation measures developed. Moreover, the physical disruptions to the environment, many of which can have significant impact on fish habitat and fisheries, must be carefully evaluated to minimize adverse impacts on renewable marine resources in the offshore area.

Countermeasures for Offshore Oil Emergencies

Most of the experience gained to date has been derived from oil spills of shipping origin within a few miles of the coastline. In these instances, the major concern has been to determine where the oil was going. If this destination was of importance from the standpoint of fisheries (shellfish, marine plants, fish nursery area, etc.), wildlife (sea birds nesting area) or recreation (beach, resort area, etc.), concerted countermeasures were undertaken to protect these areas and to recover oil. Spilled oil of coastal origin that headed offshore was tracked; however, there has been little provision made for its recovery or dispersion.

The oil spill response technology has progressed as a result of these experiences and, in eastern Canada, between ARROW (1970) and KURDISTAN (1979), the application of countermeasures for coastal spills has become more refined. The basic technology has not improved substantially. The response coordination, however, has improved considerably which has enabled a closer working relationship to develop between the scientific community and the OSC. Countermeasures for major oil spills in the marine nearshore have generally included:

(a) the physical collection of oil from beaches using absorbents (e.g. straw), pitchforks and shovels, and a "cast of thousands";

(b) the use of booms to protect sensitive areas such as harbours, water intakes, beaches, etc., and to concentrate oil for recovery purposes:

- the deployment of booms shows that "something" is being done; however, sea state, currents, tide, all impinge heavily on effectiveness of oil containment by booming;

- skimmers can collect oil contained by booms only under the mildest of environmental conditions; and

(c) the use of dispersants has limited application in areas of sensitivity for marine birds and in valuable recreational beach areas. From a fish habitat protection standpoint, the use of dispersants in the nearshore is generally not considered a rational countermeasure to employ.

In the nearshore oil spill experience, it may be concluded that the most effective countermeasures have involved the physical removal of oil from affected coastlines.

There is scant information on the effects of massive offshore oil spills on the marine environment and even less information on the countermeasures required. The most recent examples of note, namely EKOFISK (North Sea) and IXTOC (Gulf of Mexico), have not provided evidence that damage to the offshore ecosystem has been significant. In the IXTOC blowout, however, the oil coming ashore severely affected recreational beaches and did cause substantial interference with various fisheries (gear fouling, etc.). From these observations, it would appear that a massive oil spill from an offshore facility would have greater potential to affect a fishery than the ecosystem, per se, and that in the development of contingency plans this aspect should be given priority.

The most effective countermeasure for accidents arising from offshore activities is to have available as complete a data base as possible on the natural resources in the area and to have a sound knowledge of the surrounding physical environment. Information on the biology and life histories of the commercially significant marine resources in the area should be compiled. Survey data on the critical

stages in the life cycles of commercially important fish stocks (viz. spawning areas and time) should be collected and analyzed. Similarly, oceanographic and meterological data should be compiled and analyzed for the area. Combining the sensitivities of the marine resources with the physical environmental data, various scenarios can be developed, by simulation modelling, on what might occur during a major accident. More importantly, the probabilities of the released oil coming ashore on the mainland or its potential interference with commercial fishing areas could be assessed. These assessments and oil spill trajectory projections could be fine tuned as additional data derived from industry and government surveys become available.

The development of detailed (and continually updated) contingency plans itemizing points of contact, levels of authority under emergency situations, mitigation procedures, logistics and support services, communications procedures, staff training, etc. represents an essential countermeasure requirement. Because of the multifaceted industrial involvement in offshore developments, the establishment of an organization within the industrial sector such as the East Coast Spill Response Association (ESRA) is a positive approach. It should enable a more effective industrial response capability for offshore emergencies.

In addition to the development of coordinated industrial response plans, the government must ensure that an OSC, knowledgeable in the field of oil spill response actions, is immediately appointed upon notice of a major spill. He must be provided with meteorological, oceanographic, and oil spill trajectory advice as well as current advice on the marine resources at risk due to the spill. It is a governmental responsibility to ensure that a workable emergency response system is in place; without a clearly designated system, the application of any countermeasure strategies will be impossible.

A review of the current oil spill technology shows that most of the techniques that have been developed have severe limitations when considered for use offshore. Most booms, even those specifically designed for marine situations, cannot effectively operate in seas with waves above 6 feet. Even the most advanced booming systems, e.g. Vikoma Oceanpack, cannot contain oil slicks for extended periods. The feasibility of deploying booms in mid-ocean is highly questionable; booms even deployed nearshore have limited application. In some instances, where oil slick concentrations are high, recovery is possible using skimmers or other collection devices, given reasonable sea state conditions. Both booms and skimmers function optimally in protected areas where oil slicks are moderately concentrated. Although there are commercial skimmer units available for marine operations, e.g. Framo skimmers, operational performance has only been marginal.

The use of incineration and burning techniques is only applicable in the early stages of a spill and, at this time, evaporation of the lighter fractions is sufficiently high that the additional danger associated with burning is not warranted. Burning of oil is not an

option for the open sea. The question of solid waste disposal and the various methods of incinerating material collected during beach cleanup is an area of concern in the development of nearshore oil spill countermeasures.

The use of oil dispersants remains a prime oil spill countermeasure. Although much progress has been made in the manufacture of products of reduced toxicity, high biodegradability and effective dispersion, the application and performance of these products as an oil spill countermeasure remains questionable. In nearshore situations, dispersants can be effectively deployed in areas where recreational facilities are threatened or where marine bird populations require protection. The use of dispersants to protect marine resources in the open ocean has not been demonstrated nor would such an approach be cost effective. In fact, because of the inherent toxicity of even the most "acceptable" of dispersants, the massive application of these chemicals to large areas of the open sea might well be ecologically detrimental. Unfortunately, where oil dispersants have been liberally applied to oil spills in offshore waters, e.g. IXTOC (Gulf of Mexico), there has been little, if any, evaluation of effectiveness.

The use of oil dispersants remains a readily deployable countermeasure with greater logistic flexibility in application than any other oil recovery countermeasure. Under open sea conditions, it would be difficult to rationalize its application to protect marine fisheries. Dispersants are currently under development for use in breaking down the "chocolate mousse" formation characteristic of major marine spills. The efficacy of these products remains to be tested.

It would appear, therefore, that in the case of an offshore oil spill, priority should be given to shutting off the source of the leakage or blowout. Concurrently, given in-depth background on the physical oceanographic conditions that prevail and the marine resource abundance and sensitivities for the area, frequent observation and monitoring of the oil spill movement would be maintained. Should the slick(s) move toward a coastline, physical countermeasure systems would have to be readied for deployment.

A serious consequence of a massive oil spill in the open sea is its impact on commercial fishing operations. An oil spill advisory bulletin service would have to be provided for fishermen outlining where the oil would be and forecasting its movement. Dependent on the magnitude and location of the spill, an exclusion area might have to be called by fisheries managers to restrict fishing in severely oiled regions. Mechanisms for compensation, both in instances of fishing zone exclusion and gear (and catch) fouling would have to be developed (cf. KURDISTAN operation). In addition, gear cleanup centres would have to be established to de-oil nets and other fishing gear.

Conclusions

1. A major oil spill arising from offshore developments is a low probability event. Of comparable concern is the control of the chronic releases of oil from production platforms and oil transportation systems associated with offshore developments.

2. The countermeasures which are traditionally used to contain and recover oil (e.g. booms, skimmers, adsorbants, burning/incineration, etc.) are not suitable for use in the offshore. Oil dispersants can be used to mitigate offshore oil spills; however, the effectiveness of a general application of dispersants in the open sea is considered marginal. It is acknowledged that dispersants may be useful in specific situations where marine birds or recreational shorefronts are threatened.

3. Preventive measures and associated planning activities are the most useful aspects of countermeasures to be implemented. These include:

   (a) predetermined procedures being established for appointment of OSC with corresponding authority and resources;

   (b) availability of updated contingency plans detailing source of trained personnel, equipment, logistic support, communciation systems, observational reporting, capacity for oil spill trajectory plotting and analysis, liaison with scientific advisory services, etc. both to control oil released at source and to apply mitigative measures at sea if required;

   (c) availability of comprehensive data base (oceanographic, meteorological, marine resources, fishing activity, etc.) for use in the prediction of oil spill location, the deployment of mitigation measures, and the issuance of an advisory bulletin to fishermen on the position and direction of the oil slick;

   (d) continuing development of predictive capabilities for determining the trajectory and resources put to risk for oil spills originating at specific offshore locations. As data accumulates, simulation models will be upgraded to provide more accurate analyses of the potential disruption to offshore fisheries and to possible impacts on the coastal zone.

RAPPORTEURS' COMMENTS

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Blowouts

Most blowouts and the greatest volume of oil spilled are associated with development drilling and production operations as opposed to exploratory drilling. Global statistics suggest that for an oil field in the ½ to 2 billion bbl. size there is at least a 25% chance that a platform spill over 1,000 bbls. will occur at least once. For the purposes of planning, it is generally considered that the size of the Hibernia field is in this range.

It is agreed that it is all but impossible to predict the duration and total spill volume of any given blowout. The ability to calculate these would greatly assist in determining toxicity time-dose relationships. Globally, statistics show that some 60% of all blowouts "self-bridge". More specifically, sandstone reservoirs statistically tend to bridge within 20 days. However, in limestone and salt dome reservoirs this would not necessarily be the case. It should be noted that the Hibernia structure is of the sandstone type and the economically viable Sable Island structures are of the growth fault rollover type. It was the general consensus of the Consultation, however, that the probability for self-bridging is higher in exploratory wells than in producing wells.

Using flow statistics from recent blowouts, and production tests from Hibernia, it was concluded that a blowout could run in the range of 5,000 to 20,000 bbls. per day. However, it is not possible to derive a more precise figure at this time.

No general agreement or consensus was reached by the consultants on the applicability of Johnson's (1977) postulation that a 400,000-tonnes spill will occur once in 50 years, with a probability of 0.02 annually. Johnson's postulation was questioned because as technology and supervision improve with time the probability of a spill of this magnitude declines.

While most of our concern focuses on oil blowouts, attention must also be paid to gas blowouts. Sour (high sulphur content) gas is much more toxic to fish and the marine ecosystem generally than sweet gas. Since we are dealing with sweet gas for the most part in eastern Canada, it is the consensus that it poses little threat to the marine environment.

Tanker, Pipeline, and Storage Spills

The possible use of a shuttle tanker service in which "load on top" operations cannot be practised poses a potential problem of oily water

residues. It is recognized, however, that separation plants (both at sea and on shore) can leave a residue of only 0.1%. There was concern for the ecological effects of chronic oil spills. It was the general consensus, however, that such effects would be localized, inshore, and of major concern only if a large number occurred in succession. There did not appear to be consensus, however, on the cumulative effects of small spills, offshore, over time. There is general recognition that while single hulled tankers, unsegregated tanks, etc., continue to be used the risk of tanker accidents must remain of concern.

The discussants concluded that for Hibernia the worst probable case would be a total loss of all contents of a storage tank/buoy (i.e. 1 million bbls.). For Sable Island, the worst case is likely to be 75,000 bbls. of light condensate spilled from storage located on the Island or from floating storage: the Consultation did not, of course, address ecological impacts on the Island's littoral regions.

Expected Concentrations of Oil in the Water Column

Widespread concern was expressed over the lack of budgets being developed for large oil spills. It was suggested that development of oil budget information is usually very difficult during an actual spill because of time and resource constraints; the best approach would be to construct a model recognizing the limitations imposed by all the various assumptions. While the choice of AMOCO CADIZ and ARGO MERCHANT as sample spills is reasonable, there is some valid scientific argument that TORREY CANYON would provide a better model for the Grand Banks.

The major conclusion reached was that there is not sufficient data to predict accurately the distribution and concentration of oil in the water column (down to a 100 meters) over the Grand Banks. But it also seems likely that there would be sufficient concentrations to cause perturbation to biota. The stability of the Grand Banks water column in relation to concentration of oil, both within the column and ultimately in the sediments, is an important factor. In general the consensus, in this regard, was that given mixing conditions such as local storms, considerable contamination of the water column (10 to 1,000 ppb.) may occur.

Expected Concentrations of Oil in the Sediments

Whether or not significant concentrations of hydrocarbons would be incorporated into the sediments "downstream" of a spill on the Grand Banks was an important point of debate. The consensus regarding the mechanisms of transporting oil from the water column to sediments is that we know very little about the specific mechanisms involved. Of particular importance are tidal currents, for tidal mixing is integral to the contamination of sediments. While tidal mixing may not occur on the Grand Banks, it is significant on Georges Bank where tidal mixing dominates. In fact, the thermal stratification of the Grand Banks may deter the

loading of sediments, and may hold the oil in the water column. The general conclusion reached regarding the likelihood of contamination of sediments was that while contamination in the ppm range is possible it is difficult to predict the extent of that contamination.

Expected Effect upon Biota in the Water Column

At expected oil concentrations in the water column (low ppm range), it was agreed that photosynthesis in phytoplankton can either be depressed or elevated. At very low contaminant concentrations an initial increase in phytosynthesis is observed, because the hydrocarbon contaminant acts as a carbon source. At higher concentrations photosynthesis is reduced. This observation is based on laboratory study and the consensus was that it would be difficult to extrapolate it to the open ocean.

The state of knowledge regarding the effects of oil spills on zooplankton is somewhat better. At the Santa Barbara blowout (where some of the best zooplankton baseline data already existed) no significant differences were found between pre-spill and post-spill population levels. Research studies associated with the AMOCO CADIZ, however, suggested possible effects on zooplankton metabolism. However, no pre-event time series data existed in this case. Some evidence exists for temporary depression of zooplankton populations in the immediate area of the EKOFISK BRAVO blowout, but again the lack of before-after time series makes the evidence unsatisfactory.

With respect to impacts on fish, there is clear evidence from laboratory studies that given the expected range of hydrocarbons in the water column there would be lethal, as well as sublethal, effects on the eggs and larvae of teleost fish. However, adult fish would probably not be affected.

Expected Effect upon Biota in Sediments

An area of debate that was not satisfactorily resolved by this Consultation involved the bioavailability of hydrocarbons in sediments to benthic organisms, because little is known of bottom sediment oiling in the open sea. Laboratory studies provide increasing evidence that sediment-bound hydrocarbons are in fact readily taken up by benthic organisms. Research in Sweden, for example, has established that the bivalve invertebrate Macoma sp. can accumulate hydrocarbons from the sediments, and that flatfish subsequently increase their own burden by feeding on these bivalves. Similarly, sublethal effects and hydrocarbon contamination in flounder in association with oiled sediments have been described in studies at the National Marine Fisheries Center in Seattle and in other laboratories. Whether these problems exist in the field is really not known, since to date few direct measurements have been made on benthic organisms associated with oiled offshore sediments. The massive mortalities of benthic marine invertebrates that occurred during the AMOCO CADIZ

nearshore spill probably were not due to oiled sediments, but rather to toxic concentrations in the bottom waters.

For the case of the Grand Banks, the likelihood of direct impact on benthic biota from oiled bottom sediments is small. However, some potential exists for long-term, and more subtle chronic problems in localized areas of hydrocarbon contamination.

Lethal Effects

The meeting agreed that assessment of fish mortality after an oil spill requires pre-event estimates of population abundance and distribution. Present survey techniques for eggs and larvae, juveniles, and adult fish to statistically determine significant levels of mortality as a consequence of a major oil spill have limited applicability, because of constraints imposed by sampling density, conficence limits, behaviour and natural variability.

With respect to fish eggs and larvae, for example, a survey program with the station density of the Scotian Shelf Ichthyoplankton Program (SSIP) would be insufficient to statistically determine mortality associated with a major oil spill: a station density of the order of 1 per 100 square nautical miles would be required during each of three or four surveys (to cover the hatching curve) for each stock of concern. Coverage of all Scotian Shelf and/or Grand Banks spawning stocks at risk would require an escalation of existing survey efforts, perhaps by several orders of magnitude, to allow statistically significant detection of mortality from an episodic environmental perturbation.

For juveniles and pre-recruits, the limitations imposed by present levels of sampling are only slightly better for detecting mortality from a major spill. It is unlikely that mortalities less than an order of magnitude greater than the norm would be statistically detectable.

The precision of most adult stock estimates is much better, however, and would probably allow an oil-induced mortality of 25% or less to be detected.

Sublethal Effects

An alternative approach is to measure localized sublethal effects which could be related back to population dynamics effects.

It was felt that this might be accomplished by utilizing qualitative indicators for sublethal effects. Monitoring for sublethal effects would appear to have greater probability for success and cost effectiveness than expanded surveys for detection of direct mortality. However, pre-event baseline data would be required.

The concept of select indicators of sublethal effect or the idea of examining pathological approaches (i.e. fish medicine) is not new, and is the U.S. approach to the problem: the difficulty of deriving a realtionship between the observed sublethal effects and population effects is, however, very great.

The first step is to identify organisms that should be sampled for these sublethal effects and establish what the sublethal indicators should be. A thorough review of monitoring sublethal indicators is found in the "Beaufort Report" (Biological Effects of Marine Pollution and the Problems of Monitoring), which suggests that a 'suite of indicators' should be selected. Several of the more promising indicators that could be included in this suite are: (a) mixed function oxidase, (b) histopathology, (c) larval fish tail flexures, (d) varied deformations, and (e) hydrocarbon body burden. Elevated levels of mixed function oxidases have been found in field samples of fish taken from petroleum hydrocarbon contaminated waters in Newfoundland, Massachusetts, the North Sea and the Mediterranean as well as in fish taken from natural oil seep areas off the California coast. While it is generally agreed that this may be a possible approach to the problem, it is also important to consider the question of scale, especially in relation to the Grand Banks.

It was the general consensus of the Consultation that indicators which are, more or less, directly related to physiological or genetic effects and which display little temporal or spatial variability would be preferable. Monitoring for acute or chronic effects would entail carrying out surveys, concurrently from clean areas and from areas proximate to oil spill (acute condition) or oil installation sites (potentially chronic condition). While there is some concern over the required size of such a program (sampling frequency, etc.) for an area as large as the Grand Banks the same sampling intensity is not needed for the indicator approach as is required for the population survey approach.

With regard to sublethal indicators generally, it must be remembered that there already exists in the oceans a long-term buildup of pollutants and resulting sublethal effects upon biota. In the event of a major oil spill then, it might indeed be difficult to establish, especially for the purposes of compensation, that a particular effect(s) was related directly to the specific event in question. Unfortunately, this is the type of question that will be asked of fisheries scientists (i.e. what percentage of a given stock was lost in terms of possible compensation?).

Recruitment Variability

The Consultation established clearly that it is very unlikely that the effects of a single oil spill, however large, could be distinguished from natural variability with respect to recruitment in commercially-important species. The greater the species-specific recruitment variability the less chance there is for identification of oil spill induced effect upon recruitment. Therefore, because of this natural recruitment

variability and earlier identified sampling inadequacies, it would be all but impossible to detect (statistically) changes in recruitment into the fishery caused by eggs and larval mortality. The general consensus was, however, that perhaps effects on localized stocks in enclosed or restricted waters (i.e. herring) could be detected.

The timing and location of spawning activity and subsequent distribution of eggs and larvae is imperfectly known for most stocks. However, the areal extent of an oil spill is likely, for the most part, to be only a fraction of the total area occupied by the eggs and larvae of most species. It is concluded that even if the spill covered the full area of eggs and larval distribution, and resulted in a 50 - 100% mortality of eggs and larvae of a weak year-class, it would not have detectable effect upon recruitment. Only in the case of the largest year-class sizes would the detection of significant recruitment impact be expected. However, it is not known whether larvae throughout a "patch" have an equal probability of reaching recruitment.

The area with greatest potential for the coincidence of a major oil spill and commercially-valuable finfish eggs and larvae is the Grand Banks generally and the Hibernia area more specifically. Generally, the oil slick from a spill at this site would more or less coincide in space (and time if occurring during the spring) with the 2J3KL cod eggs and larvae. While it is likely that both the slick and the eggs and larvae would both occur within a broad band, little is really known of the vertical distribution of cod eggs and larvae within the water column. These data are prerequisite to any understanding of impact. It is concluded that given the rather shallow water over the Bank, it was possible that eggs and larvae could be distributed throughout the column.

Another general area identified where oil spills might affect eggs and larvae is the slope of the Continental Shelf. There is a concern about the prospects for significant development on the slope of the Shelf which thereby places it directly in line with the dynamics of the Shelf break, and all that it implies.

In a consideration of impairment of fish recruitment, indirect ecosystem effects also have to be examined in addition to direct mortality. With respect to phytoplankton and zooplankton, it is the general consensus that given all the uncertainties regarding the dynamics of oil in the open ocean plus the uncertainties of what is occurring in the food chain, it is impossible to define quantitative effects at this time. With respect to primary production and its subsequent effect upon fish stock biomass, it can be stated generally that suppression of primary production by an oil spill would not result in detectable recruitment changes. The changes may be negligible.

The Consultation was adamant that a distinction must be made between "no statistically detectable effect" on stock recruitment and "no effect". There is a concern that "no detectable effect" may be interpreted by some as no effect on fish stocks as a consequence of a major oil spill. In

fact, a post-spill survey would probably yield considerable numbers of dead, moribund or deformed fish larvae and perhaps even juveniles and adults. This demonstrable impact notwithstanding, it is quite unlikely that the loss to the population could be measured in a statistically convincing manner and shown to have had a subsequent effect upon recruitment into the fishery. This possibility is further complicated in that recruitment occurs several years after the impact and the fishery operates for a number of years on any given year-class (depending on life expectancy).

In this regard, the Consultation also wished to emphasize that because recruitment impacts, for the most part (species such as capelin notwithstanding), occur in the future, it is necessary to stress the utmost importance of continuation of ongoing, regular research and surveys during a spill. In other words, scientists working on long-term relevant research should not be diverted in order to react to the short-term crisis.

Consequences for Fishing Operations

In relation to offshore development activities, the fishing industry will ask four questions:

Will the number of fish available be reduced?
Will fish be tainted?
Will their fishing gear be fouled by oil and/or debris?
Will fishing areas and support areas onshore be pre-empted?

These questions will be asked within the framework of possible compensation. With respect to compensation, it was generally agreed that in the event of a major spill, DFO will want to know the "cost to the fishery". It is agreed, however, that determining such a figure would be difficult, if indeed not impossible, at this time given our state of knowledge. The recent KURDISTAN incident resulted in claims in excess of one million dollars mainly for items such as inshore fixed gear fouling, and fouling of accessories. It must also be pointed out that in the case of an offshore spill, in addition to the above mentioned types of inshore problems, there would be international as well as domestic implications. These problems are judged to be significant only if the spill continued for a long time or at a time when a foreign fleet was in the process of filling its quota.

The other area of possible significant "cost to the fishery" relates to recruitment impairment, which will occur in the future and far from the actual spill site. It may indeed be difficult, if not impossible, to get satisfactory compensation even if significant changes in recruitment can be detected. It was generally conceded that it would be difficult legally to prove cause and effect. It must also be pointed out that there may very well be a statute of limitations (perhaps 2 years) even if cause and effect can be shown five years after a spill incident. While it is

recognized that offshore operators are required to post a bond of $30 million for east coast activities, it is generally felt that such an amount would be insufficient in the case of a major incident having the magnitude of an AMOCO CADIZ or IXTOC I. While it is the consensus of the Consultation that compensation for reduced catches, because of depressed recruitment levels, would indeed be difficult to obtain, it is the general feeling that the fishing industry would have little trouble obtaining compensation for such things as fouled gear, contamination of catch, etc.

In order to examine, in detail, our present capabilities to cost a spill in terms of effect upon recruitment in a commercially-viable species, a simple scenario is developed using the case of the 2J3KL cod stock (or northern cod stock complex). For the 2J3KL cod stock, an impacted year-class (eggs and larvae) would not be recruited into the fishery for 4-5 years. If a 50% mortality of larvae is assumed, this level of impact would result in a detectable loss to the fishery of some 10 - 15% in subsequent years only in the case of an optimistic year-class occurring in the spill year. In the case of a small year-class, the impact would not be detectable. The fact that density dependent factors could be at work during the pre-recruitment years complicates and possibly contradicts the exercise of costing a spill in this manner. In certain scientific quarters it is hypothesized that factors affecting cod recruitment levels may, on the Grand Banks, be set over the first three years, due to density dependent factors.

In terms of consensus regarding the topic under consideration, the following points clearly evolved:

1. It is unlikely that stocks will become tainted by oil in the open ocean with the possible exceptions of those stocks identified immediately above. It is possible, however, that catches may become contaminated by fouled gear. Apart from the visible presence of oil, there are presently no established standards or guidelines for rejecting contaminated catches.

2. There is a high probability that fishing gear may be fouled by oil and that significant damage to, and loss of, gear caused by debris and underwater obstruction is likely.

3. It is unlikely that there will be any need to modify Canadian or foreign harvesting strategies or fishing plans except in instances involving extended spills or those occurring near the end of quota-filling activities.

4. Exclusion of fishing activity, while potentially being significant in a localized sense, should not be significant overall.

Countermeasures

The limitations imposed on countermeasures in the open ocean by the physical environment were recognized. Because of the general ineffectiveness of containment and clean-up techniques, the importance of preventing major accidents was stressed. In addition to ensuring that the required preventative measures are in place, the Consultation also stressed the need for DFO to address the socio-economic issues perhaps to be faced in the fishing industry (i.e. gear fouling, catch tainting, exclusion zones, fleet avoidance and pre-emption, etc.). Also offered as important in this overall planning is development of a data base on the fishing industry's use of those portions of the continental shelf demonstrated as having the most potential for hydrocarbon development.

It was concluded that contemporary measures (i.e. booms, skimmers, burning, absorbing, herding and dispersing) offer little real hope of success. Although there is a measure of consensus regarding the limitation of countermeasures generally in the open-ocean environment of the Atlantic coast, there was considerable variation of professional opinion regarding the environmental pros and cons of dispersant use.

Within certain quarters the opinion is clearly that because aerial application of dispersants is one of the few countermeasures that can be undertaken in the open ocean, therefore the concept of dispersant-use cannot be discounted. However, there is a major question of whether or not dispersants are in themselves more of a toxicity problem than oil. It was also argued that there is little evidence in the literature that dispersants effectively disperse oil throughout the water column in the open ocean, especially in cold water environments.

With respect to the dispersant toxicity debate, there did seem to be a general consensus that dispersants have tended to drop in toxicity over the last decade or so, but in doing this they probably have become less effective in dispersing oil. It also seems to be the consensus of the Consultation that it is highly questionable whether dispersants used in the cold, harsh, open Atlantic Ocean environment are any more effective in dispersing oil than the natural processes at work (i.e. wind, wave climate, etc.).

This lack of consensus is undoubtedly due not only to the difference in professional opinions but also the experience and institutional backgrounds of the Consultation discussants. Where there is general consensus, however, is with respect to the timing of dispersant use and the need for accelerated research and development activities. Regarding the time of use, there is agreement that dispersants should not be used immediately upon a spill occurring, but rather allowance should be made for the evaporation of the lighter, more toxic ends. Subsequent action would then disperse only the heavier less toxic ends into the water column. However, the dispersants must be used before there is any further significant weathering of the oil to maximize the potential for toxicity to biota.